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DEPARTMENT OF OCEAN ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

THE IMPACT OF GROUP TECHNOLOGY-BASED SHIPBUILDING METHODS
ON NAVAL SHIP DESIGN AND ACQUISITION PRACTICES

by

John Sutherland Heffron
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THE IMPACT OF GROUP TECHNOLOGY-BASED SHIPBUILDING METHODS
ON NAVAL SHIP DESIGN AND ACQUISITION PRACTICES

by

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B. S., Computer Science, Louisiana State University (1974)

M. S., Applied Mathematics, University of Arkansas (1976)

Submitted to the Department of
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In Partial Fulfillment of the Requirements
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and

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at the

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May, 1988

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JOHN SUTHERLAND HEFFRON

Submitted to the Department of Ocean Engineering
on May 6, 1988 in partial fulfillment of the
requirements for the Degrees of Naval Engineer and
Master of Science in Ocean Systems Management

ABSTRACT

Modern shipbuilding practices in the United States have evolved from the requirement to build naval ships as economically as possible while still retaining the desired level of quality and the ability to fulfill naval mission requirements. The highly competitive environment that shipbuilders are now in has further stimulated their search for more efficient and productive ship construction methods. As a result, group technology-based shipbuilding methods have been developed and implemented over the last few years. These new construction technologies have profound effects on the manner in which naval ship acquisition is, or should be, conducted. In particular, there are serious consequences regarding engineering and design, CAD/CAM, ship work breakdown structures, and cost and schedule control systems.

First, a brief history of naval ship design and acquisition practices, leading to a description of the current shipbuilding technologies, is given. Then the effects these technologies have on the above-mentioned areas of the naval ship acquisition process are described. Included are detailed examples of how modern shipbuilding methods have affected selected naval ship acquisition programs. Finally, changes in some of these areas will be recommended so that modern ship construction and outfitting techniques can be more fully meshed into the total naval ship acquisition process, thereby enhancing the productivity gains these techniques have already made.

Thesis Supervisor: Henry S. Marcus, D.B.A.

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The author extends his gratitude and thanks to Professor Hank Marcus whose guidance and support made this thesis possible.

to my wife, Elizabeth, and my daughter, Sarah

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CHAPTER 1

INTRODUCTION

1.1 Background

In April of 1986 the President's Commission on Defense Management published a report on defense acquisition [1]. The commission had been formed, in part, to help deal with Department of Defense problems related to overpriced spare parts, test deficiencies, and cost and schedule overruns. Their analysis led to the conclusion that the defense acquisition process has fundamental problems that must be corrected. These problems are deeply entrenched and have developed over several decades as a result of an expanding bureaucracy with its tendency for overregulation. As a result, too many weapon systems cost too much, take too long to develop, and, by the time they are fielded, feature obsolete technology. The typical acquisition cycle time, from the time a mission or system requirement is defined until the system is operational, has grown to twelve or fifteen years or more for complex systems.

In the opinion of the President's commission it should be possible to cut this cycle time in half by implementing the following recommendations:

- * streamline acquisition organization and procedures,
- * expand the use of commercial products,
- * increase the use of competition,

- * enhance the quality of acquisition personnel,
- * balance cost and performance,
- * stabilize programs, and
- * use technology to reduce costs and schedules.

It is the last recommendation that is central to this thesis. In the broadest context this thesis is about the effects modern construction technologies have on defense acquisition practices. In particular it is about the effects they have on naval ship acquisition practices and shipbuilding productivity.

Many discussions of naval ship acquisition begin with the acknowledgment that major defense weapons systems are the most technically complex of any in existence. And it can be argued that the most complex of weapons systems are naval ships.

Ships are the largest mobile objects on Earth and naval ships represent an integration of a multitude of major and minor related systems of which many are extremely complex in their own right. A nuclear-powered aircraft carrier is over 1100 feet long, displaces over 90,000 tons of sea water, and is propelled at speeds in excess of 30 knots by power plants rated at over 200,000 shaft horsepower. It is also an airport with a capacity of 100 or more jet aircraft. Additionally, it is a self-contained city with a population of over 5,000 people. Its multi-reactor nuclear plant, various electronic systems and aircraft launching and recovery sys-

tems take years to design and test before they are ready for installation and use in the fleet.

Unfortunately, the complexity of the hardware in question is perhaps only matched by the complexity of the bureaucracy and process concerned with the acquisition of the hardware. During World War II, the entire Navy Department in Washington, D. C., charged with directing an effort involving, at the peak of the war, thousands of ships, consisted of about 200 people. Today there are in excess of 20,000 people in the Washington, D. C. area employed by the Navy. The active fleet today consists of close to 600 ships.

As indicated earlier, it commonly takes twelve to fifteen years to conceive, develop, design, and construct a new U. S. Navy ship class. The problems of long range fiscal forecasting and engineering development in an unstable political and economic environment, coupled with rapid technological advances, are mind boggling. Any technology or methodology that offers to reduce the cycle time and the costs of the acquisition process deserves close study and development.

1.2 Thesis Overview and Objectives

Modern shipbuilding practices in the United States have evolved from the requirement to build naval ships as economically as possible while still retaining the desired level

of quality and the ability to fulfill naval mission requirements. The highly competitive environment that shipbuilders are now in has further stimulated their search for more efficient and productive ship construction methods. As a result, group technology-based shipbuilding methods have been developed and implemented over the last few years. These new construction technologies have profound effects on the manner in which naval ship acquisition is, or should be, conducted. In particular, there are serious consequences regarding engineering and design, CAD/CAM, ship work breakdown structures, and cost and schedule control systems.

The second chapter of the thesis begins with a discussion of the four distinct strategies employed in defense systems acquisition since World War II. The reader should gain from this material background knowledge about the naval ship acquisition process and environment. Included is a description of the naval ship design process as viewed by the Naval Sea Systems Command (NAVSEA), the organization within the U. S. Navy responsible for acquiring ship systems. Next is a brief history of the development of modern shipbuilding methods in the United States, their subsequent transfer to and improvement in Japan, and finally their return to the United States. The chapter ends with a technical overview of ship producibility and modern shipbuilding methods. Included here is a discussion of group technology; product-oriented work breakdown structures; planning for

production; process flow lanes; zone construction, outfitting, and painting methods; and accuracy control. Since this material has been recently collected in a comprehensive treatment of modern ship production methodology and practices, the discussion is brief [2].

With the above information established, Chapter 3 then considers the impacts modern shipbuilding methods have on the naval ship acquisition process. The particular areas considered are design and engineering, CAD/CAM, ship work breakdown structures, and cost and schedule control systems. Included are detailed examples of how modern shipbuilding methods have affected selected acquisition programs. The programs considered include the TAO 187 class fleet oiler shipbuilding program, the DDG 51 class destroyer shipbuilding program, and the SSBN 726 class Trident ballistic missile submarine shipbuilding program.

Based on the discussions of Chapter 3, the final chapter offers conclusions and recommendations on how the naval ship acquisition process may be changed so that the improvements thus far made in ship construction methods may further reduce ship acquisition construction times and costs.

REFERENCES TO CHAPTER 1

1. "A Formula for Action, A Report to the President on Defense Acquisition by the President's Blue Ribbon Commission on Defense Management", April, 1986.

2. Storch, R. L., Hammon, C. P., and Bunch, H. M., Ship Production, Cornell Maritime Press, Centreville, Maryland, 1988.

CHAPTER 2

NAVAL SHIP ACQUISITION AND SHIPBUILDING, WORLD WAR II TO PRESENT

2.1 Post World War II Naval Ship Acquisition

2.1.1 Introduction

An overview of the structure and process of naval ship acquisition in the United States since World War II is presented in this section. Four distinct periods are identifiable: the conventional period (until the early 1960's), the total package procurement period (also called the concept formulation/contract definition or the McNamara period, after the then Secretary of Defense Robert S. McNamara) which began in the early 1960's and ended about 1969, the post McNamara period which ended about 1979, and the current period. Although the major policies and characteristics of the four periods differ considerably, it is not always possible to categorize a particular ship acquisition project as being a result of the policies of any one period. For example, the nuclear-powered aircraft carrier project (Nimitz Class) was conceived during the conventional period, continued through the total package procurement and post McNamara periods, and remains an ongoing project. It has characteristics of all four policy periods. The ships were designed primarily by the Navy ("in house") with the aid of a design agent, typical of the conventional, post McNamara,

and current periods. Some of the ships were constructed under a multi-ship, multi-year contract, which is characteristic of the total package procurement and post McNamara periods.

Thus, as the different periods are described, it should be remembered that ship projects are long (twelve to fifteen years or more) and often transcend major acquisition policy shifts. Additionally, like any large bureaucracy, new policies and strategies from top management (the Secretary of Defense) often do not take effect at the working level (the ship projects) for two or three years, if at all.

2.1.2 The Basic Process

Although policies and organizational structures for designing and acquiring ships for the United States Navy have changed over the years, the basic process remains much the same. Also, though differing in details and nomenclature, the acquisition of ships, at the most basic level, is similar to the acquisition of other major defense systems. A need is identified; a requirement based on that need is established; a weapon system is selected, designed, developed and constructed to fill the requirement. Sometimes technological breakthroughs motivate a new acquisition but attempts are made to ensure that a legitimate need, and not "technology push", precedes the development and construction of a new system.

The Navy and other services are charged with identifying needs and defining, developing, and producing systems to satisfy those needs [1]. Establishing overall acquisition policy, passing on the validity of needs, and monitoring the performance of the services in carrying out the policy is the responsibility of the Office of the Secretary of Defense [2].

National defense policies and objectives are provided by the Secretary of Defense and translated by the Joint Chiefs of Staff into military policies and objectives. Planning and programming by the services are keyed to these objectives. Evaluation of the Joint Chiefs of Staff guidance may lead to research and development objectives formulation by the services to satisfy deficiencies in their capabilities to perform their respective missions [3]. The Program Objectives Memorandum (POM) is the budget for this effort and for the weapons systems which emerge from the research and development efforts [4].

The POM is part of the Department of Defense Planning, Programming, and Budgeting System (PPBS). Funding for weapons systems is obtained through the PPBS. However, a series of approvals by intra-service organizations and the top level Defense Systems Acquisition Review Council (DSARC) is also currently required before a new weapons system is built. The role of the DSARC will be discussed in more detail later in this section.

2.1.3 The Conventional Period

At the end of World War II the U. S. Navy deactivated most of its fleet and ship production virtually ceased. During the Korean conflict most of the required ships were reactivated World War II-era ships. Finally, in 1952, the Navy directed the construction of 31 major ships [5].

Acquisition practices were characterized by an iterative design process accomplished by the Navy or by an independent design agent working for the Navy. Their products included a complete construction bid package with little documentation. The major emphasis was on ship performance and production contracts were often split between two or more shipbuilders. There was little involvement by the Office of the Secretary of Defense. The acquisition process was basically decentralized to the service level.

Initially, the entire design and procurement effort would be coordinated by a few people. They relied on various functional organizations to perform the necessary design and acquisition work required. Different organizations would be responsible for various systems on the ship. For example, the Bureau of Ordnance was responsible for weapons. Later, starting with the Polaris ballistic missile program, the trend was toward project manager-type organizations.

Production contracts were spread among several shipyards to facilitate more rapid delivery of ships and to aid in preserving the shipbuilding and ship mobilization indus-

trial base. Of course, regional political and economic pressures also played a role.

As shown in Figure 2.1, the conventional approach involved Navy personnel formulating a ship concept. This activity included cost and feasibility studies and possibly advanced research and development. Assuming budgetary approval was obtained, increasingly refined design stages, termed preliminary design and contract design followed. This approach did not employ systems analysis techniques.

The resulting product was a bid package, including complete contract plans and specifications. The bid package could result in any number of procurement contracts. Lead ships were often built in Navy shipyards. The amphibious ships LPD 7 through 15 were built under four contracts by two shipbuilders. Exclusive of the costs of changes to the contracts, these ships were delivered to the Navy at an average of 25% over the initial contract price and 27 months behind schedule [7]. Escalation due to inflation and claims against the government accounted for most of the cost overruns. These results became increasingly typical. Low or negative profit performance precipitated many of the claims. The basis for the claims was usually a dispute over interpretation of the complex and detailed contract specifications. Also, production facilities were becoming antiquated and uncompetetive in the world market. Support of the ships was costly and often inadequate due to lack of standardiza-

Conceptual Preliminary Contract Detail Production
Studies → Design → Design → Design →

|← Navy →|← Navy or Design Agent →|← Shipbuilder →|

Contract Definition

Concept Ship- Ship- Ship- Detail Production
Formulation → builder A builder B builder C → Design →

|— Navy —| |— Shipbuilder Competition —| |— Single Shipbuilder —|

```
graph LR; A[Feasibility Studies] --> B[Concept Design]; B --> C[Preliminary Design]; C --> D[Lead Ship Contract Design]; D --> E[Lead Ship Detail Design and Production]; E --> F[Follow Ship Contract Design, Detail Design and Production];
```

Feasibility Studies → Concept Design → Preliminary Design → Lead Ship Contract Design → Lead Ship Detail Design and Production → Follow Ship Contract Design, Detail Design and Production

Timeline markers:

- Navy (from Feasibility Studies to Preliminary Design)
- Navy with Shipbuilder(s) (from Lead Ship Contract Design to Follow Ship Contract Design, Detail Design and Production)
- Shipbuilder(s) (from Feasibility Studies to Follow Ship Contract Design, Detail Design and Production)

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tion among ships of a given class and among classes of ships.

2.1.4 The Total Package Procurement Period

A radically different approach to weapons design and acquisition was formulated in the early 1960's by the Office of the Secretary of Defense under Robert S. McNamara. The new approach centralized major decision authority in McNamara's office. Objectives were:

- a) optimization of cost effectiveness by using systems analysis techniques;

- b) reduction or elimination of contractor claims against the government by using contractor-prepared performance oriented specifications instead of government-imposed detailed specifications;

- c) reduction of cost overruns by transferring financial risk to the contractors for the design and acquisition phases through the use of fixed price contracts;

- d) significant capitalization increases in shipbuilding facilities by using multi-ship, multi-year contract awards to a single shipbuilder (This was expected to provide long term financial security, thus enabling large-scale capitalization and expansion of facilities to accommodate delivery schedule demands);

- e) reduction of unique systems and subsystems proliferation which had resulted from split production contracts;

f) introduction of producibility and innovation into designs by having the shipbuilder design the system;

g) lower acquisition costs by taking advantage of the learning curve effect made possible through single-producer serial production; and

h) more accurate total cost estimates and reduction of poor ship support by making the contractor responsible for all on-board systems, crew training, initial repair parts, support facilities, and other logistics details [8].

A project manager-type organization was directed for all major programs [9]. As outlined in Figure 2.1, the services still conducted research and development and identified the desired performance characteristics of the weapon system during the concept formulation stage. Assuming approval by the Secretary of Defense, a contract definition period followed. A request for proposal (RFP) was prepared by the Navy and issued to selected shipbuilders to prepare design analyses based on the specified performance characteristics. The RFP contained both mandatory and desirable performance specifications and were supposed to encourage alternatives and stimulate initiative and creativity on the part of the contractors [10].

After evaluation of the proposals by the Navy, normally two or more contractors were awarded fixed price contracts to develop a complete shipbuilding proposal. Required in these proposals were contract plans and specifications,

detailed construction plans, management plans, and a complete analysis of life cycle costs [11]. Life cycle costs are the total costs of acquisition and ownership, including development, production, deployment, operation, and maintenance.

No longer than six months was allowed for the contract definition phase. This was followed by a source selection process during which a detailed analysis of the proposals was conducted by the procuring service. Negotiation was conducted with one or more of the potential contractors. At the conclusion of the evaluation period a recommendation was sent to the Office of the Secretary of Defense to award a multi-year, multi-ship contract to the selected contractor, to conduct further contract definition, or to defer or abandon the effort. The single contract award was fixed price, with or without incentive clauses.

The Navy conducted three total package procurement ship competitions. The Fast Deployment Logistics ship was not funded by Congress. The Amphibious Helicopter Assault ships (LHA class) and the SPRUANCE class destroyers were funded and their acquisition programs completed. Litton Industries won all three competitions [12].

The USS Spruance was the first ship delivered under either contract and was accepted by the Navy in 1975. However, the acquisitions were beset by many of the same problems that characterized defense weapons procurement during

the previous period - large cost and schedule overruns. This was particularly true of the LHA contract. The first LHA was delivered years behind schedule, even after the original contract was renegotiated, allowing for a higher contract price and later delivery date.

By the late 1960's, cost and schedule overruns and performance shortfalls of new weapons systems were daily newspaper fare. In 1971 the Department of Defense Comptroller conducted a survey of 35 major development and production programs [13]. Only two of the programs were found to be on, or ahead of, schedule. That same year the General Accounting Office made a survey of 61 weapon systems and found that cost estimates for them had increased \$33.4 billion over the initial estimates [14]. Contractor costs soared and profits plummeted. The term "contractor bailout" became a household word as one producer after another threatened to cease production unless relief from the fixed price contracts was provided.

By 1970 a number of studies had found serious flaws in the management of the weapons acquisition process. As a result, on May 28, 1970, Deputy Secretary of Defense David Packard issued a memorandum which stated that the total package procurement approach to developing and acquiring major weapon systems was unsatisfactory and that a new policy would soon be established [15]. The Navy was still years away from delivery of its first ship procured under

the canceled policy. The overall conclusion was that the long term objectives of total package procurement were never met. It is a fact that the sole source multi-year contracts resulted in the construction of a new shipyard by Litton Industries in Pascagoula, Mississippi. However, Litton had problems in developing an adequate design and production force and in making the new facility operationally efficient during the performance period of their contracts.

2.1.5 The Post McNamara Period

The major policies and trends of ship acquisition following the demise of total package procurement included:

- a) emphasis on constrained design ("design-to-cost"),
- b) emphasis on proven hardware ("fly-before-you-buy"),
- c) required review and approval to proceed by the DSARC at key milestones,
- d) a prohibition against total package procurement,
- e) improvement in cost estimating,
- f) flexibility in contract type and liberalization of contract escalation (due to inflation) clauses,
- g) use of contractors for "in-house" ship design, and
- h) tailoring of acquisition approaches to each project.

The cancellation of the key top level policy directive [16] for the total package procurement period in 1970 left a guidance void that was not formally filled until the issu-

ance of Department of Defense Directive 5000.1, "Acquisition of Major Defense Systems", on July 13, 1971. It was during this same period that then Chief of Naval Operations Elmo Zumwalt directed the rapid development of a large class of austere, relatively inexpensive Guided Missile Frigates (FFG class) to bolster the size of the rapidly diminishing fleet [17]. They provided the "low" end of the so called "high mix/low mix" fleet concept.

After a year of feasibility studies, Admiral Zumwalt directed that the design would not violate constraints which were set on the average follow ship acquisition cost, fully loaded displacement, and maximum number of accommodations [18]. Performance capability above the minimum specified was to be traded-off to stay within the constraints. This method of ship design, commonly termed "design-to-cost", was revolutionary to the Navy, but was common in industry for new product development.

A major program consideration was that "discrete cost elements (e.g., unit production cost, operating and support cost) shall be translated into 'design to' requirements" [19]. In October, 1973 the major services' material commands issued the "Joint Design-to-Cost Guide" [20]. This directive required that "design-to-cost" methodology be used for most major systems.

Historically, performance requirements for new ships had been dictated by the Chief of Naval Operations to the

material command in brief "single sheet characteristics" [21]. These were used by the material command to develop preliminary designs and cost estimates leading to more detailed characteristics statements, and ultimately to procurement specifications [22]. Costs were considered but were usually secondary to maximizing performance. "Design-to-cost" elevated the importance of acquisition cost to the same level as performance in the design process. As a result, a new performance-cost tradeoff dialogue between the customer (Chief of Naval Operations) and producer (Chief of Naval Material) organizations was required. "Top Level Requirements and Top Level Specifications for the Development of Naval Ships", Chief of Naval Operations Instruction 9010.300, was issued early in 1974. It detailed a procedure which provided for a working level group (the Ship Acquisition and Improvement Council) to develop the performance parameters for a baseline ship which would meet the established mission requirements. The group also specified allowable variations in performance parameters and alternative system selections for the ship class [23].

After a period of feasibility studies during which the impact of the alternative performance parameters and systems selections were evaluated, the Chief of Naval Operations prepared a draft of the Top Level Requirements (TLR). This document was revised as the Naval Material Command (parent command of NAVSEA, for whom acquisition projects worked

directly) developed a conceptual design for the ship class and provided cost and design information to the Chief of Naval Operations. Assuming approval from the Chief of Naval Operations to proceed with a selected design, a "conceptual baseline" and a "cost goal" for the average follow ship acquisition were presented to the DSARC, which is composed of high level officials in the Office of the Secretary of Defense. If DSARC and Secretary of Defense approval were given to proceed into preliminary design, a draft Top Level Specification was initiated by the Naval Material Command. This companion document to the TLR translates the TLR into a physical ship description [24].

The large performance shortfalls, schedule delays, and cost increases referred to earlier in this chapter were at least partially a result of overly optimistic estimates of ultimate system capabilities and the time required to design and perfect them [25]. There had been a great deal of reliance on "paper studies" rather than on actual performance demonstrations. Thus, a major program consideration of the post McNamara period was to ensure that achievement of program objectives was assured prior to full-scale production [26]. The goal was to eliminate technical and cost risks. A supporting Department of Defense directive was issued in January of 1973 to establish test and evaluation policy for the acquisition of defense systems [27].

The key practice which grew from recognition of the need for increased test and evaluation during the acquisition process was prototyping. This is sometimes known as the "fly-before-you-buy" policy and was used in the Navy's air-cushioned landing craft (LCAC) program. However, it is not feasible to build and evaluate prototypes prior to beginning follow ship design and production for large ships. The time required, small number of ships usually involved, and threat of obsolescence dictated a modified approach.

In such a modified approach, the FFG program developed a plan which provided for:

- a) early construction of land based test facilities (LBTFs) for complete propulsion and combat systems testing, and

- b) a delay of two years between construction contract awards for the lead and follow ships [28].

This plan permitted testing of the two major high risk subsystems prior to installation on the lead ship and time to incorporate changes resulting from the test and evaluation program into the design of the follow ships. The LBTFs were also useful for crew training.

The DSARC was mentioned earlier and will be explained more fully now. It was established in the Office of the Secretary of Defense by then Deputy Secretary of Defense David Packard in May, 1969 [29]. The purpose of the council

was to review and evaluate the status of major defense systems acquisitions at critical milestones.

Formal documentation for the DSARC reviews and decisions was provided by the project-prepared Decision Coordinating Paper (DCP), formerly called the Development Concept Paper. It was a summary document that recorded the primary information on a program. Included were thresholds, risks, a statement of need, alternatives, rationales for decisions, and affordability considerations. When signed by the Secretary of Defense, it provided the authority for the service to proceed to the next step in the program. His decision set the limits of authority within which the project was obligated to stay [30].

A long series of intra-service briefings and reviews was generally required of an acquisition project prior to a DSARC presentation.

As more and more contractors failed to perform under the total package procurement fixed price contracts, the need for increased government involvement with its contractors was realized. The fixed price contracts and the lack of government involvement in the design supposedly transferred any financial risks from the government to the contractor and thus the role of the acquisition projects was basically that of monitoring, with little control leverage.

During the post McNamara period the top level acquisi-

tion policy directive specified that the contract type should be consistent with all program characteristics, including risk. Also stipulated was that cost-type contracts were preferable where substantial development effort was involved [31]. The use of cost-type contracts allowed the possibility of increased government involvement.

Apart from the lack of governmental control leverage resulting from fixed price contracts, attempts at effective contractor cost and schedule control by the projects had historically been hampered by:

- a) a reluctance of the contractors to share what it considered to be proprietary information,

- b) the preoccupation of project managers with the annual funding approval process and the continuity of funds control as opposed to cost control,

- c) the proliferation of various information and cost control systems imposed on contractors by the different services and projects (validity of the information was often lost in the translation from the contractor's system to the government imposed system(s)),

- d) the exclusion in the reporting systems of the budgeted cost of work performed,

- e) improper allocation of contractor costs between overhead (indirect) and direct costs,

- f) inability of the project personnel to evaluate the detailed information they require of the contractor, and

lack of correspondence between reported data and the contractor's own data,

g) retroactive changing of financial plans to conform to work performed to date (the so-called "rubber baseline"), and

h) contractor use of nonintegrated work breakdown structures and nonintegrated charts of cost accounts (sum of budget dollars for work at one level may exceed budget at next higher level). [32]

In a survey conducted during the 1960's, it was found that most program managers were satisfied if their funds control reports indicated that funds were being expended at the planned monthly rate and their PERT network reports [33] showed no significant schedule slippage [34]. Schedule network reporting based on starts rather than completions, untimely or inaccurate reporting, and the lack of performance of scheduled noncritical path work all served to build in cost overruns which often went undiscovered until it was too late to take any meaningful cost or schedule control action.

In 1967 the Department of Defense issued a directive entitled "Performance Measurement for Selected Acquisitions" [35]. The system may be summarized as follows:

a) Part One of the program requires that contractors use internal planning and control systems that meet minimum government criteria. These criteria are called the "Cost

and Schedule Control Systems Criteria" (CSCSC).

b) Part Two of the program requires that contractors regularly submit Cost Performance Reports (CPRs) which contain information on the budgeted cost of work performed to date. The criteria themselves do not require the submission of any reports to the government, but specify the reporting capabilities which contractors' internal systems must have, and the types of data the systems should be able to produce. The contractor is free to design this internal planning and control systems to correspond to the manner in which he organizes his work units and assigns responsibility for performing work [36].

The goal of CSCSC is to provide a reliable means of measuring schedule variance, SV, and cost variance, CV, periodically over the course of a particular contract. This is done by calculating the following values, referenced to the same time period:

ACWP = actual cost of work performed

BCWP = budgeted cost of work performed

BCWS = budgeted cost of work scheduled

CV and SV may then be calculated as follows:

$$CV = ACWP - BCWP$$

$$SV = BCWS - BCWP$$

During the performance period of a contract, a positive CV indicates a cost overrun and a positive SV indicates a schedule slippage. Either situation is a cause for project

office concern.

An important concept in the reporting criteria is that the contract cost status reports must be based strictly on the number of jobs completed to date.

Five years after the CSCSC had been developed, only 16 defense contractors had been certified as complying with the criteria. The Navy was singled out by the Senate Armed Services Committee as being particularly slow in implementing the new system [37]. In 1971 an additional twenty contractors complied with the criteria and all three services were actively implementing the program and training personnel in its use [38].

As indicated, the FFG program pioneered many of the reforms of the post McNamara period. In addition to those aspects already discussed, a key element of the period was to select a lead and a secondary contractor early in the design effort. The function of the lead shipbuilder was to assist in the in-house design effort and ultimately to build the lead ship under a cost plus fee type of contract. The purpose of this was to introduce producibility into the design, to promote design familiarity and acceptance of performance characteristics by the contractor, and to reduce the development time [39].

The secondary shipbuilder was involved to prevent the introduction of producibility bias by the lead shipbuilder,

which would result in unfair advantage when bidding on the follow ship contracts, and to provide a fallback position in case lead ship contract negotiations failed. When the first increment of follow ship fixed price contract bids were received in 1975, the Navy was dismayed to receive bids from only two contractors - the lead and secondary contractors. Moreover, the bid prices were well in excess of the "design-to-cost" constraint. The lack of participation in the bidding by other shipbuilders and the high bids submitted were due to one or more of the following:

- a) shipyard loading by other (mainly merchant ship) contracts,
- b) poor profit and loss experience on previous contracts,
- c) a reluctance to accept the required involvement by the government in the contractor's procedures and operations,
- d) fear that the escalation provided for inflation would be insufficient, as it had been in the past, and
- e) the Navy's cost estimate was far too low.

These difficulties in the FFG program are generally considered to have been the result of past project problems and not an indication of failure of the post McNamara period reforms. It is interesting to note that the FFG 61, the last of the FFG 7 class, is due for delivery late in 1988.

2.1.6 The Current Period

If the total package procurement and post McNamara periods can be described as periods of radical changes in ship acquisition policy, then the current period is one of evolutionary change. It can therefore be described most conveniently in terms of the ways in which it differs from the previous period.

During the 1980's the watchwords of defense procurement have been "competition" and "acquisition streamlining". The Navy has responded to DoD initiatives in these areas by creating within the Navy Secretariat the positions of Navy Competition Advocate General (CAG) and Navy Specification Control Advocate (SPECAG). Both of these positions are under the Navy Acquisition Executive, who is the Assistant Secretary of the Navy for Shipbuilding and Logistics (ASN(S&L)) [40].

The Competition in Contracting Act of 1984 requires that full and open competition be used wherever possible in procurement of services and material. Each ship acquisition project manager (SHAPM) must therefore ensure that competition is provided for in his acquisition plan (AP). Any deviation from full and open competition must be justified by the SHAPM and approved by ASN(S&L). There are seven exceptions to full and open competition and they include:

- * existence of only one responsible source

- * unusual or compelling urgency
- * industrial mobilization
- * international agreement
- * authorization or requirement by statute
- * national security considerations
- * and public interest considerations. [41]

Since ship acquisitions rarely fall into any of these categories, and since domestic commercial ship production is almost nonexistent, competition among the Navy's shipbuilders has become intense over the last decade. This competition partially accounts for the recent development and use of more efficient shipbuilding methods by U. S. shipbuilders.

However, there is concern in the U. S. defense industry that the emphasis on competition is being carried too far. There is evidence in recent procurements that, in the face of increasing competitive pressures, some contractors have been "low balling" or "buying-in" to contracts with the hope that anticipated contract changes will offer the opportunity to recoup what would otherwise have been an almost certain loss. There is concern within both industry and the government that such practices may be the prelude to a return to the bitter claims era of the 1960s and early 1970s [42].

Acquisition streamlining is any action taken to reduce cost and time of acquisition while maintaining or improving

product quality. The objective of streamlining is to identify, develop and implement improvements in the acquisition process. This includes ensuring that only innovative and cost-effective acquisition requirements are included in shipbuilding solicitations and contract specifications. Management requirements specified in the contract should be the minimum required to satisfy program needs while allowing the contractor the flexibility he may need to incorporate improvements into his shipbuilding system. The concept of acquisition streamlining calls upon industry to be involved early in the acquisition process by recommending cost-effective solutions to shipbuilding problems.

SHAPMs are required to fulfill the objectives of acquisition streamlining in their specification and contract development. After contract design they must certify to the SPECAG that all streamlining requirements have been met [43].

The basic steps of naval ship design prior to the issuing of an RFP are largely unchanged from those of the post McNamara period, as can be seen in Figure 2.2. [44] This figure illustrates the dialogue that takes place between the Chief of Naval Operations (OPNAV) and the Naval Sea Systems Command (NAVSEA). An important element of the organization in OPNAV that has yet to be mentioned is the Ship Characteristics Improvement Board (SCIB). It includes

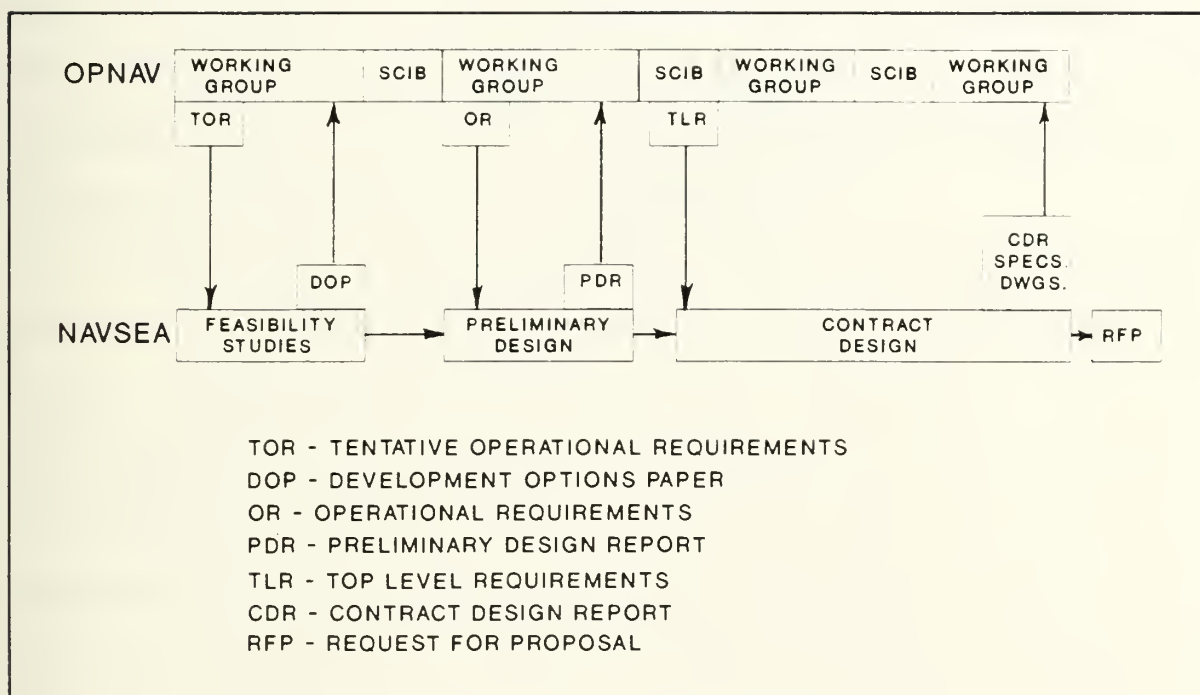


Figure 2.2 OPNAV/NAVSEA Ship Design Dialogue [44]

all the principal warfare sponsors and other high-ranking members of OPNAV's staff. It is their job to pass judgment on all ship designs proposed by NAVSEA [44].

Examination of the post World War II acquisition strategies has revealed that the acquisition approaches employed in the decades of the 1950s, 1960s, and 1970s represent not only fundamentally different strategies from each other, but also that for each of these periods there was a reasonably well-defined strategy. The success or failure of these strategies may be debated but there is general agreement as to what these approaches were supposed to be.

Unlike these previous periods, there is no one dominant strategy for accomplishing naval ship design in the present decade. Rather, the precise approach to be used on a new ship acquisition is decided on a case-by-case basis at the beginning of each ship acquisition and is stated in that program's AP. As a result, the contract design approach employed on the SSN 21 design differed markedly from that used on the DDG 51 design. And LHD, SWATH TAGOS, MSH, and MHC all have their own approaches. This evolution in acquisition strategies is shown in Figure 2.3.

It might be argued that unnecessary confusion and delay occurs at the beginning of each new ship design until the strategy is determined. However, the technical and management complexities associated with the design of a modern

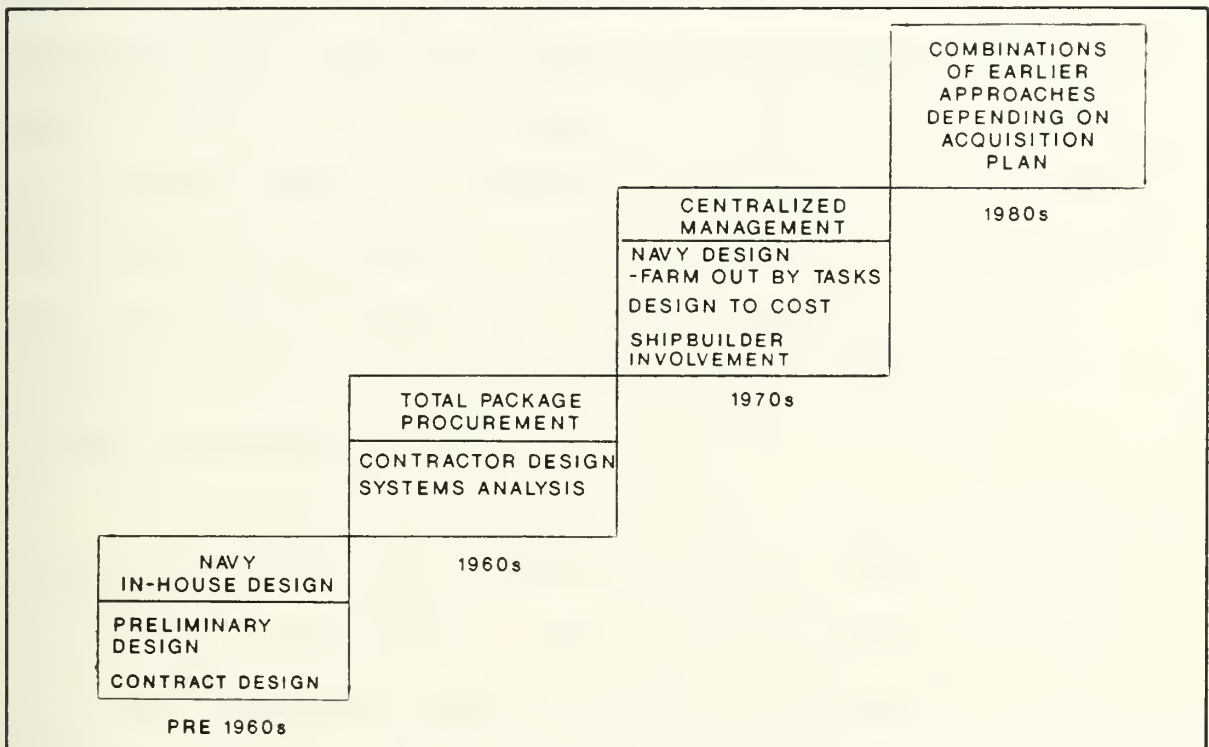


Figure 2.3 Summary of Naval Ship Design Approaches [44]

warship are such that this approach will be increasingly necessary in the future.

2.2 A Brief History of Modern Shipbuilding Methods

In 1942 the German Navy was sinking Allied shipping faster than the Allies could produce ships. However, by mid-1943 that problem had been turned around and American shipyards were producing ships faster than they were being sunk. This success was largely the result of industrial engineering techniques brought to the shipbuilding industry by industrialist Henry J. Kaiser. He and his organization had never built a ship prior to 1942 and therefore they brought few preconceived notions to the problem of efficiently producing ships.

He introduced the concept of group technology, that is, organizing work by the problems inherent to manufacturing, to American shipbuilding. This product-oriented approach, vice the traditional systems-oriented approach, allowed Kaiser's yards to achieve benefits normally associated only with production lines [45]. Welding was done in a downhand position only, both because this was faster and because there was a scarcity of experienced welders during the war. Also to facilitate welding, ship's bows were built sideways, deckhouses upside down and the sides of ships on the ground, rather than from high, often precarious, and costly scaffolding. The governing principle was to organize the work

to fit the worker.

As a result of his methods, Kaiser's Liberty ships were delivered in two-thirds the time and at three-fourths the cost of those built by traditional shipbuilders [46].

After World War II, Elmer Hann, a former general superintendent at one of Kaiser's yards, brought Kaiser's methods to Japan, whose shipyards were intentionally left untouched by the Allies during the war. After the war, Japan desired to use its shipbuilding capacity and Elmer Hann taught the Japanese the organization of work in accordance with the principles of group technology, welding without distortion to control costs, and the importance of college-educated middle managers trained in the entire shipbuilding system. With these methods and only pre-World War II shipyards, Japanese yards were producing 40 percent of the world's total shipbuilding tonnage by 1964 [47].

A contemporary of Hann's was Dr. W. Edwards Deming, a professor of statistics from New York University. He introduced the notion of statistical control methods (SCM) to Japanese industry. Statistical control radically improved quality, laid the foundation of modern ship construction methods, and made it possible to develop automated and specialized welding.

With the application of SCM, management systems began to furnish workers with meaningful indicators of how work processes performed. For the first time, it was possible to

evaluate the impact on work processes of even the smallest innovations. This, in turn, gave rise to quality circles, and as a result, people at all levels in a modern Japanese shipyard participate in problem solving on a daily basis [48].

Dr. Hisashi Shinto initially worked for Elmer Hann as his chief engineer. After Hann and other Americans returned home, Shinto became the head of the Ishikawajimi-Harima Heavy Industries Co., Ltd. (IHI) shipyard at Kure. Using techniques he had learned in the United States, together with a Japanese material-control system and SCM, Dr. Shinto developed an improved shipbuilding system based on Kaiser's logic. By 1979, the IHI system enabled a worker to achieve in one hour the work for which three man-hours were required in a traditional U.S. shipyard [49].

This same technology, highly refined, is now coming back to the United States, partly due to the Merchant Marine Act of 1970. This act contained the authority for the joint government/industry National Shipbuilding Research Program (NSRP), whose numerous publications have detailed much of the modern Japanese methods. Also, shipyards such as Avondale Industries, Inc. and Bath Iron Works, Inc. have directly contracted with IHI in the hope of improving the productivity of their yards.

This section has identified the start of modern shipbuilding methods in the United States, how they were trans-

ferred to Japan and, after significant development, how they are returning to the United States. It is now appropriate to consider just what these modern shipbuilding methods are.

2.3 Modern Shipbuilding in the United States Today

2.3.1 Introduction

This section contains an overview of ship producibility and modern shipbuilding methods. Included is a discussion of group technology; product-oriented work breakdown structures; planning for production; process flow lanes; zone construction, outfitting, and painting methods; and accuracy control. For a much more complete treatment of these topics the reader is directed to reference 2 of Chapter 1.

2.3.2 Group Technology

Group technology began as an outgrowth of an attempt to develop a more efficient system of classification and coding for use in the management of industrial processes. It is an innovation in the field of management of manufacturing processes, not just a technique of keeping track of material, parts, subassemblies, modules, etc.

The purpose of addressing group technology here is to better understand shipbuilding and how productivity can be improved in the shipbuilding industry.

Two definitions of group technology are offered:

- 1.) Group technology is the logical arrangement and

sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production [50]. This definition emphasizes a systems approach to management and, as such, supports a central concept, put forth by Mitrofanov, that the group technology process is a manifestation of the systematization and generalization of the experience of a manufacturing industry [51]. The systems approach also emphasizes the importance of integration of all parts of the company.

2.) Group technology is a technique for manufacturing small to medium lot size batches of parts of similar process, of somewhat dissimilar materials, geometry and size, which are produced in a committed small cell of machines which have been grouped together physically, specifically tooled, and scheduled as a unit [52]. This definition is worth dissecting, phrase-by-phrase:

* small to medium lot size batches - Group technology is not applicable to lot sizes which can be efficiently produced on an assembly line. Rather it is a means of realizing certain benefits of mass production for essentially similar small batch interim products. It is not mass production.

* similar process - This implies categorizing interim products by problem areas or by the problems common to their manufacture. These problem areas include the specific type of work and similar production techniques, tools, and worker

skills.

* somewhat dissimilar materials, geometry, and size - This means that the same problem area does not imply identical material, shape, and size. For example, installation of pipe and air-conditioning ducts may pose the same problems and therefore be installed by the same crew.

* processed in a committed small cell of machines which have been grouped together physically - The main idea conveyed by this phrase is parallelism. A cell or group within the shipyard is responsible for completing all aspects of a given block, unit, or module, regardless of overlapping functional systems involved. Therefore, subassemblies can be completed simultaneously, rather than systems being completed sequentially.

* specifically tooled - This implies that each work station, including its workers, is specifically equipped for only the particular job at hand.

* scheduled as a group - This implies beginning work on a particular unit or subassembly only when all resources for the job are in hand. This has important implications for management, engineering, and material control. In particular, these functions must be more responsive to production control than they had been when using traditional system-oriented shipbuilding methods.

Group technology is not the same thing as classifica-

tion and coding. However, classification of the elements of production is perhaps the first step in the successful implementation of group technology [53]. One classification system, the product work breakdown structure, is discussed in the next section.

Classification and coding are often used as if they were the same thing. They are not and the distinction is that the code is the vehicle or mechanism by which a classification system is made usable.

2.3.3 Product-Oriented Work Breakdown Structures

A work breakdown structure is a classification system. Ones commonly used in shipbuilding are either systems or product-oriented. The U. S. Navy currently uses a systems-oriented breakdown called the Expanded Ship Work Breakdown Structure (ESWBS). It is used throughout the entire ship life cycle and is used in the areas of cost, weight, specifications, system function and effectiveness, design, production, and maintenance [54]. All major classification groups are defined by a three-digit code as described in Table 2.1. The last two groups are used primarily for cost estimating and progress reporting. Each major group is broken down into hierarchical subdivisions called subgroups and elements as shown in Figure 2.4.

A classification scheme to subdivide work in accord-

000	General Guidance and Administration
100	Hull Structure
200	Propulsion Plant
300	Electric Plant
400	Command and Surveillance
500	Auxiliary Systems
600	Outfit and Furnishings
700	Armament
800	Integration/Engineering
900	Ship Assembly and Support Services

Table 2.1 The Navy Expanded Ship Work Breakdown Structure (ESWBS) Major Groups [54]

(Group)	100 - Hull Structure
(Element)	101 - General Arrangement
(Subgroup)	110 - Shell and Supporting Structure
(Element)	111 - Shell Plating
(Element)	112 - Shell Plating, Submarine Non-Pressure Hull
(Subgroup)	120 - Hull Structural Bulkheads
(Element)	121 - Longitudinal Structural Bulkheads
(Element)	122 - Transverse Structural Bulkheads

Figure 2.4 An Example of the ESWBS Organization [54]

ance with an interim product view is a product-oriented work breakdown structure (PWBS) [55]. Parts and subassemblies are grouped by common permanent characteristics, and classified by both design and manufacturing attributes. The classification system typically specifies parameters, such as form, dimensions, tolerances, material, and types and complexity of production machinery operations. Classification by product aspects relates a part or subassembly to a zone of a ship and also to work processes by problem area and by work stage. Therefore, product families are determined by both design and manufacturing attributes.

First, PWBS divides the shipbuilding process into three basic types of work: hull construction, outfitting, and painting, because each imposes its own unique set of manufacturing problems. These types of work are further subdivided into fabrication and assembly classifications. Within the painting classification, fabrication applies to the manufacture of paint, and assembly refers to its application. The assembly subdivisions are naturally linked to zones and are the basis for the zone dominance seen in shipbuilding management.

Second, PWBS classifies interim products in accordance with their needs for resources. Resources include material, manpower, facilities, and expenses.

Third, PWBS classifies interim products by the four product aspects needed for control of production processes.

Two product aspects, system and zone, are means for dividing a ship design into planned and manageable portions. Each zone is usually addressed by a separate work package. The other two product aspects, problem area and stage, are means for dividing the work process from material procurement to complete ship delivery. These four terms may be defined as follows:

* System - a structural function or an operational function of a product, e. g., longitudinal bulkhead, fire main system, lighting system, etc.

* Zone - an objective of production which is any geographical division of the total product, e. g., superstructure, engine room, etc., and their subdivisions or combinations, e. g., a structural block or outfit unit, a subassembly of either, and ultimately a part or component.

* Problem area - a division of the production process into similar types of work problems such as:

- by feature (e. g., curved vs. flat plate, steel vs. aluminum material, small vs. large diameter pipe)

- by quantity (e. g., job-by-job vs. flow lane)

- by quality (e. g., grade of worker required, grade of facilities required)

- by kind of work (e. g., marking, cutting, bending, welding, painting, testing, cleaning)

- by anything else that defines a different work problem.

* Stage - a division of the production process by sequences, i. e., substeps of fabrication, subassembly, assembly, erection, and outfitting.

The classification system and categories described above are illustrated in Figure 2.5.

After an interim product has been identified by its product aspects, it is necessary to evaluate its efficiency as a work package. This efficiency is a function of the time it takes to complete the product, the number of units of resources, and the quality of the work environment (e.g., downhand vs. overhand welding). If the efficiency is not high enough, the work package must be redefined. This iterative development and evaluation of work packages through the planning process is illustrated in Figure 2.6.

2.3.4 Planning for Production

In order to successfully include production considerations in preplanning or planning, each shipyard must develop its own build strategy. This strategy reflects the capabilities, practices, and preferences of the yard, modified to fit the specifics of the ship to be built. It helps to define and prioritize decisions about the shipbuilding project at its earliest stages. An overview of design and material definition, the importance of overlap of these stages with production, and their impact on PWBS will be treated in this section.

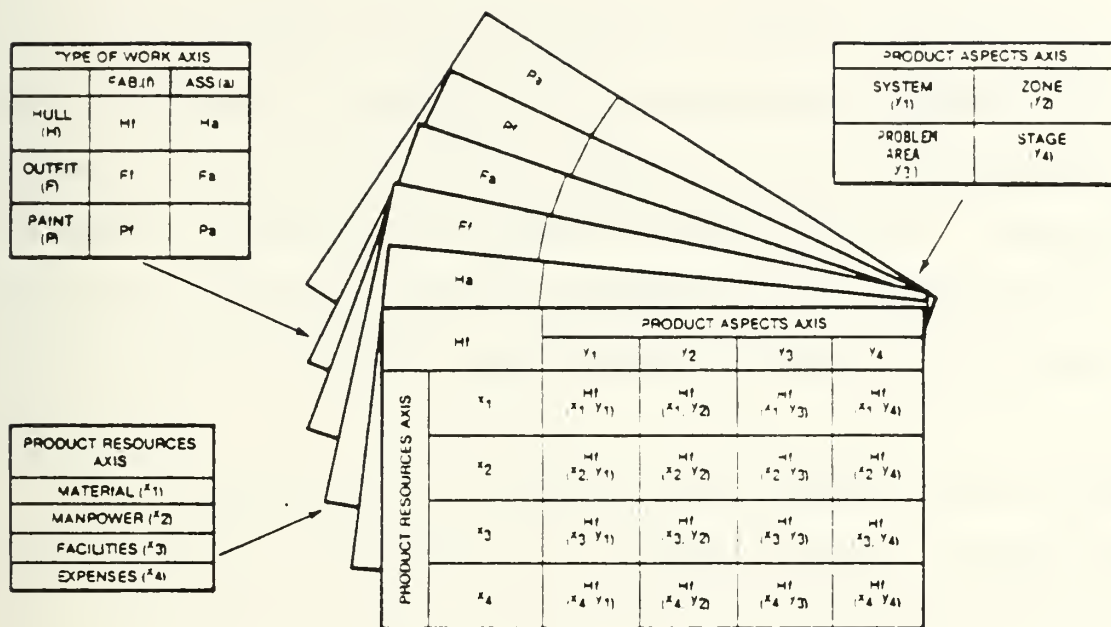


Figure 2.5 Elements of the Three-dimensional PWBS Matrix [55]

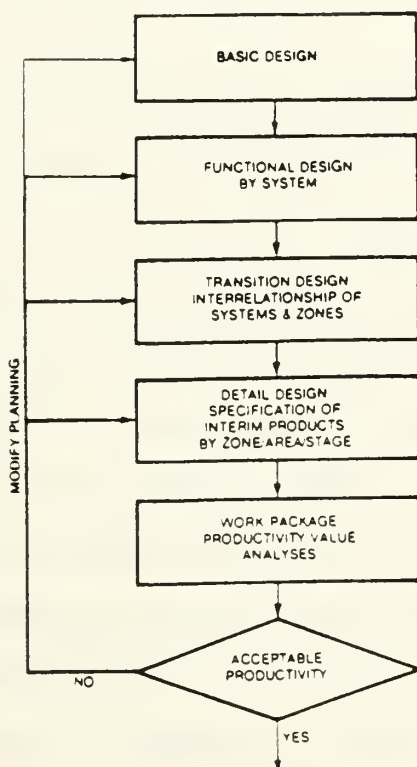


Figure 2.6 Iterative Development of Work Packages [55]

Significant overlap of design, material procurement, and production is essential for reducing the overall construction time, but overlap reduces the time available to organize information developed by the designers. Therefore, from the beginning, design information must be formatted to more fully anticipate needs relating to material and production.

In addition to overlap in time, there is an overlap between functional systems and product aspects. PWBS allows for this dual grouping. Each phase of the shipbuilding management cycle (estimating, planning, scheduling, execution, and evaluation) is addressed in terms of system versus zone orientation.

Figure 2.7 indicates the primary emphasis, either system or zone, of each of the phases in the shipbuilding process. The process begins with a systems orientation. This is a view of the ship as a whole, broken down by systems. During preliminary design the key transformation from system to zone orientation takes place. Later, near the end of the contract, the transformation back to a system orientation occurs to permit overall ship evaluation, in terms of both systems performance and cost performance. The ability to make these transformations is key to the successful implementation of group technology-related or PWBS-related shipbuilding.

Design, which is considered part of planning, is

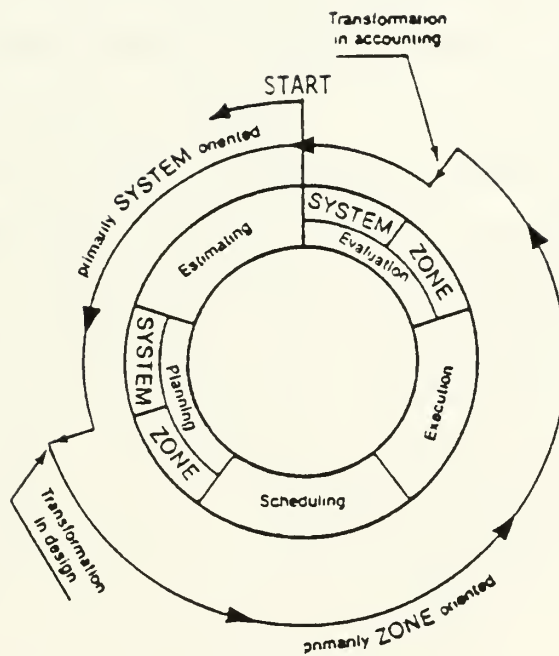


Figure 2.7 System and Zone Orientation in the Shipbuilding Process [55]

divided into:

- * Basic Design (In Navy parlance this includes all design through contract design.)

- * Functional Design - up to the detail level

- * Transition Design - from system to zone

- * Work Instruction Detail - down to the worker level

These divisions of the design process are described in Figure 2.8.

The design process continues until each zone is broken down to components that are to be purchased and to material requirements for parts that are to be fabricated.

This is the lowest hierarchical level of classification.

The most important point is that each successive stage comes closer to transforming the developing design into a format better suited to the end users' needs.

Design as well as production groups are organized according to classes of problems in such a way as to complement the established zones. Each design group prepares key drawings, working drawings, and material lists in accordance with the established zones. Within each group it is essential to have good "horizontal" communication between the different engineering disciplines. The group focuses on composite drawings, which show how the ship is to be built, and material lists. System arrangement drawings are no longer needed, as the interference-free and simplified composites, either drawings or scale models, are developed directly from diagrammatics. Therefore, the principles of

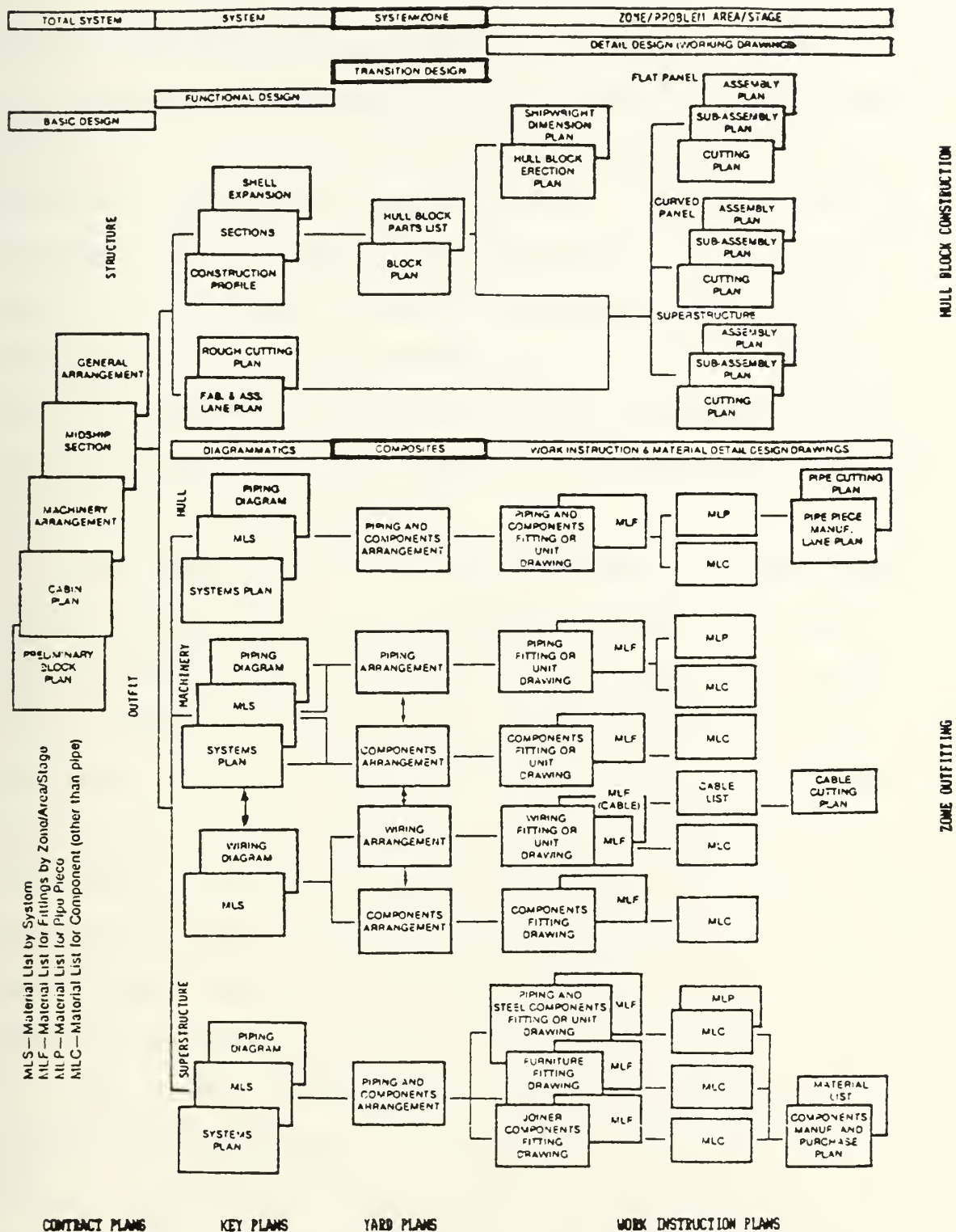


Figure 2.8 PWBS Ship Design Process [55]

group technology apply to design as well as to production.

Zone-oriented scheduling is necessary to control work flows so that interim products are produced in such a way as to anticipate only immediate needs. The scheduling must coordinate all production work and allow time for the transportation of interim products to the next assembly site. The goal is to minimize buffer storage while at the same time creating no bottlenecks or controlling paths. Thus, integrated schedules are essential for fabrication through final outfitting and testing.

Shipyards and the Navy desire accurate progress reporting of schedule as well as manpower and material costs. This is facilitated by having relatively small work packages. Progress reporting and cost collections are zone-oriented. This gives both the yard and the Navy accurate indications of work completed so that work and resources required for completion can be forecasted. In order for the Navy (or shipyard) estimators to obtain realistic costs on a system basis some sort of allocation of costs back to the system level must be established and agreed upon.

This indirect collection of costs by system may be viewed as a degradation of system cost data, particularly in the area of manpower costs. However, the PWBS philosophy argues that a PWBS-based system produces more accurate data due to inherently better control. Material usage and costs can fairly easily be collected by system and cost, particu-

larly where functional designers are required to identify all materials for each diagrammatic.

2.3.5 Process Flow Lanes

The process flow lane or process lane concept may be defined as the "categorization and separation of similar types of work, and the subsequent development of work centers specifically designed to efficiently perform that kind of work" [56]. The keys to effective process flow lanes are planning, scheduling, and material control. The goal of the shipyard is to establish process flow lanes which produce repeatable interim products and which are uniformly loaded, both for an individual shipbuilding program and for other shipyard projects as well. Figure 2.9 shows process flow lanes for a notional shipyard. The process flow lanes are organized by classes or problem areas and demonstrate how their end products must integrate for zone-oriented production. Fabrication shops and assembly shops are grouped along the various process flow lanes.

Hull construction has historically been the responsibility of a single shop with a single trade union, so the introduction of hull block construction in process flow lanes is fairly easily managed in most American shipyards. However, the establishment of outfitting process flow lanes and the integration of the entire ship assembly process cuts across traditional shop and trade union lines. As a result,

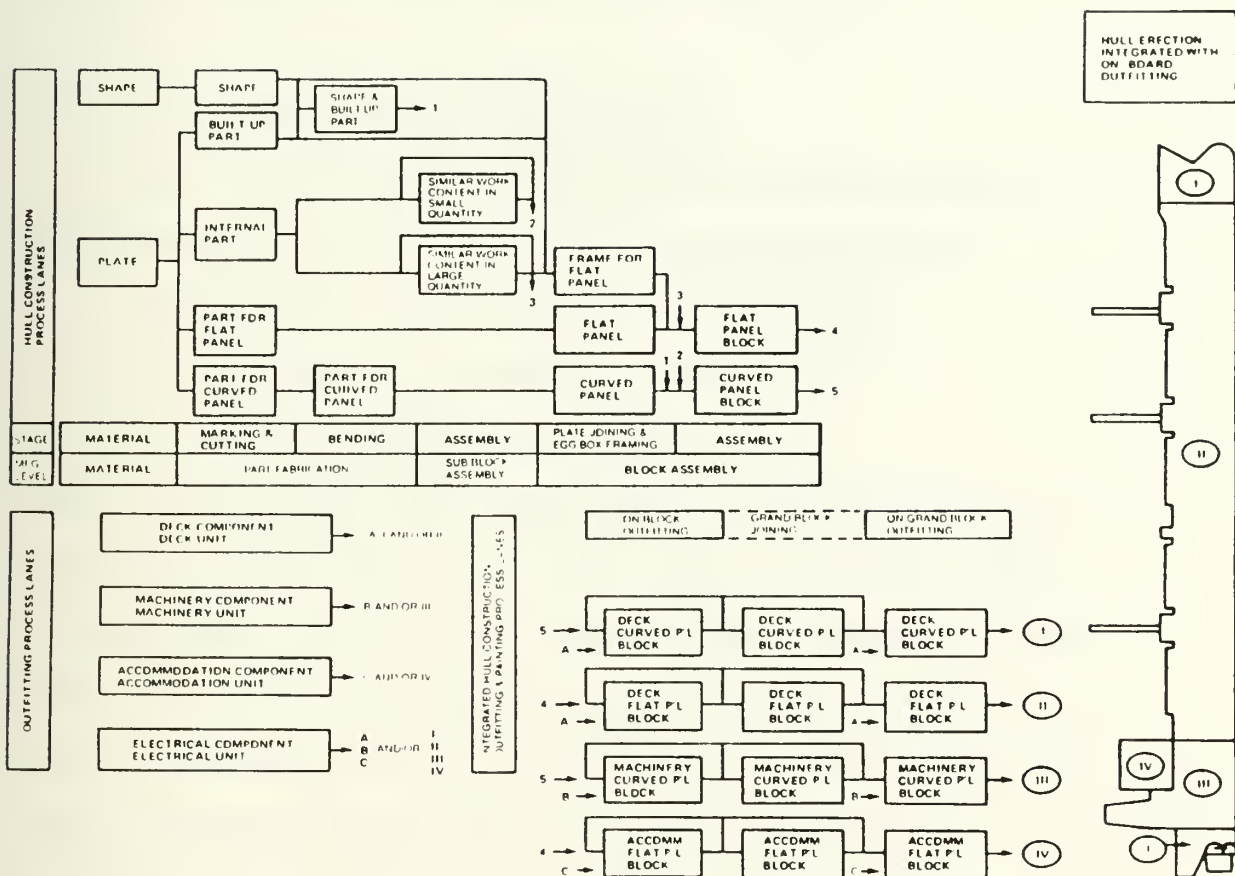


Figure 2.9 Process Flow Lanes in Modern Shipbuilding [55]

progress past the modern hull block construction stage has been slow in most yards. In shipyards that have completely adopted zone-oriented methods, many trades have been combined in various ways: a ship fitter may do some welding, a pipe fitter may do some electrical work, etc.

2.3.6 Zone Construction Methods

The product-oriented breakdown of ship construction accommodates the following zone-oriented methods:

- * Hull Block Construction Method (HBCM)
- * Zone Outfitting Method (ZOFM)
- * Zone Painting Method (ZOPM)

Also, since large quantities and varieties of pipe pieces, ventilation ducting, wire ways, etc. are needed, PWBS accommodates problem area-oriented family manufacturing (FM), or pipe piece family manufacturing (PPFM). This is shown diagrammatically in Figure 2.10. The integration of HBCM, ZOFM, and ZOPM represents the application of the principles of group technology to shipbuilding. Together they form a total shipbuilding system. PPFM is different in that it represents the application of group technology to a specific shop. For more information on PPFM the interested reader is directed to reference 2 of Chapter 1. HBCM, ZOFM, and ZOPM will now be discussed briefly.

Optimum block (or zone) size is the basis for control

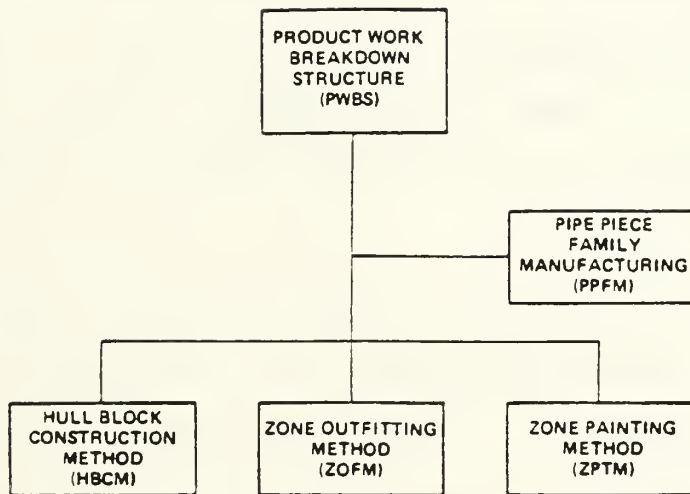


Figure 2.10 PWBS Components [56]

in HBCM. But blocks also directly impact zone outfitting and painting. As a result, the determinations of block dimensions and location, compared to other interim products, have the greatest influence on shipbuilding productivity.

Blocks are designed so that:

- * they are assignable to one work package group
- * they are inherently stable, balanced structures
- * they require minimum working times
- * they have maximum accessibility for outfitting and painting.

Also, they should be similar in work content as much as possible so that work can be distributed evenly throughout the fabrication and assembly levels. Planners and designers should also try to maximize the amount of downhand welding and design the blocks to be the largest size capable of being handled by the shipyard's lifting and moving equipment.

It is usually practical to plan hull construction in seven levels as shown in Figure 2.11. Work assigned to the grand block level minimizes the duration required for erection on the ways. For maximum productivity, the main work flow path must be level-loaded.

Within each level other than the top two, the interim products are examined for similarities in their product aspects. Then they are grouped by these similarities in order to further modularize the production process, justify

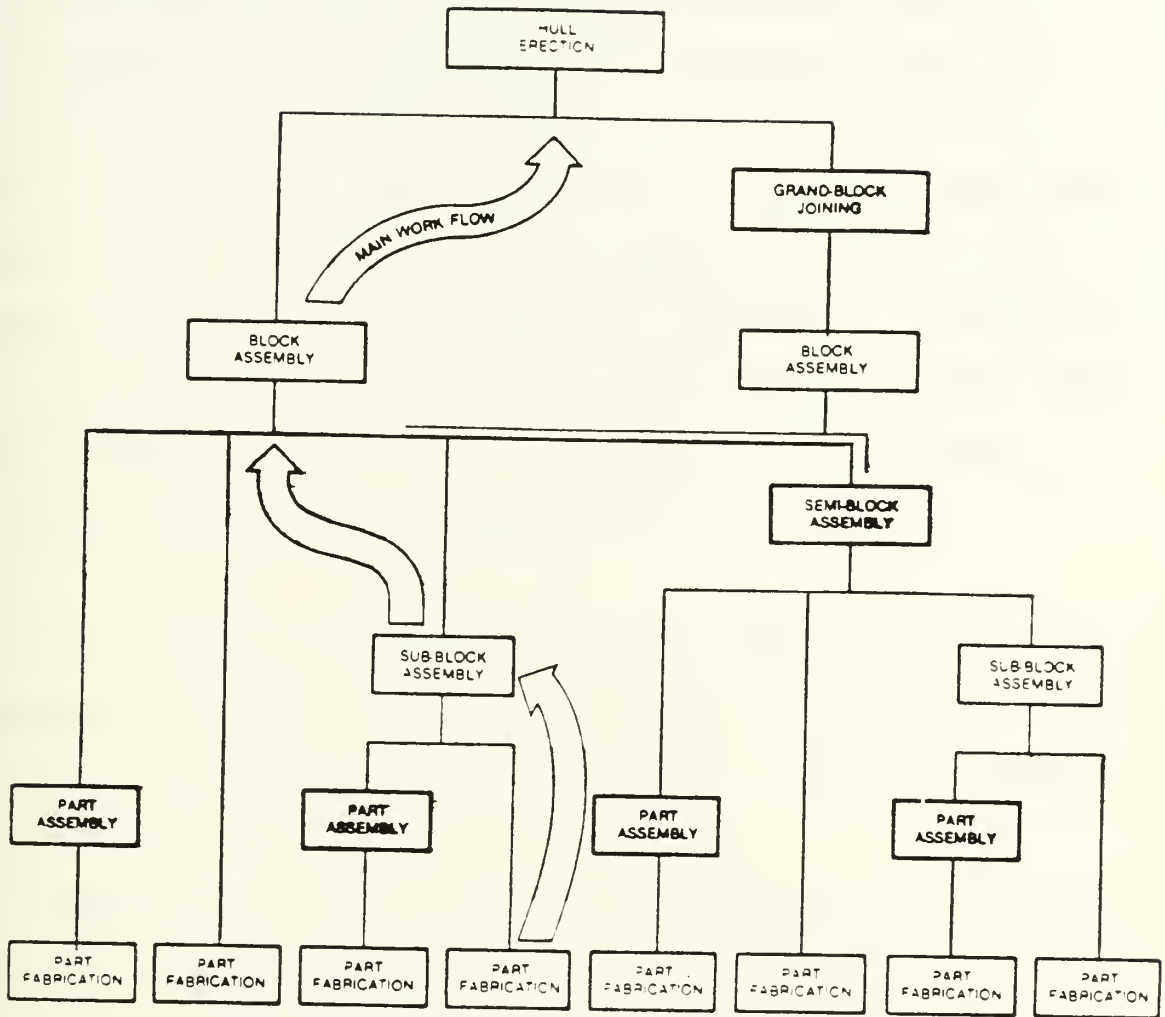


Figure 2.11 HBCM Manufacturing Levels [57]

expensive but highly efficient facilities, and achieve manpower savings. Typical groupings by product aspect are shown in Figure 2.12. Horizontal combinations characterize the various types of work packages that are needed for work to be performed at each level. Vertical combinations of work packages denote the process flow lanes for hull construction work flow which correspond to the process flow lanes in Figure 2.9. Maximum productivity is obtained when work is evenly allocated to work packages grouped by their product aspects, and there are quick responses to potential work imbalance, such as shifting workers among manufacturing levels and/or process flow lanes, authorizing overtime, or even short-term schedule changes [57].

Since both follow the same logic, ZOFG is a natural consequence of HBCM. Shipyards which have advanced to the point of using ZOFG assemble most outfit components independent of or on hull blocks.

ZOFG planners must consider the block zones previously defined for hull construction. Then they are usually otherwise free to devise zones which best suit their system. So, while there is generally greater freedom in defining outfit zones, specifying zone by problem area by stage work packages affords absolute control of work, even in a confined area of the ship that contains multiple systems. Outfitting packages which correspond to a zone/problem area/stage orga-

PLANT LEVEL	MFG LEVEL	PRODUCT ASPECTS											CODES		
		ZONE	AREA					STAGE				ZONE	AREA	STAGE	
1	7	SHIP	FORE HULL	CARGO HOLD	ENGINE ROOM	AFT HULL	SUPERSTRUCTURE	TEST				SHIP NO	BLOCK CODE	STAGE CODE	
							ERECTION								
2	6	BLOCK	FLAT PANEL	CURVED PANEL		SUPERSTRUCTURE	BACK PRE-ERECTION		NIL		GRAND BLOCK CODE	GRAND BLOCK CODE	STAGE CODE		
							PRE-ERECTION		NIL						
							JOINING		NIL						
3	5		NIL	FLAT	SPECIAL FLAT	CURVED	SPECIAL CURVED	SUPERSTRUCTURE	BACK ASSEMBLY		NIL		BLOCK CODE	BLOCK CODE	STAGE CODE
									ASSEMBLY						
									FRAMING		NIL				
4	4	NIL		SIMILAR WORK CONTENT IN A LARGE QUANTITY		SIMILAR WORK CONTENT IN A SMALL QUANTITY		PLATE JOINING		NIL		SEMI-BLOCK CODE	SEMI-BLOCK CODE	STAGE CODE	
								BACK ASSEMBLY		NIL					
								ASSEMBLY							
5	3		SUB-BLOCK	SUB-BLOCK PART	BUILT-UP PART		BACK ASSEMBLY		NIL		SUB-BLOCK CODE	SUB-BLOCK CODE	STAGE CODE		
							ASSEMBLY								
							BENDING		NIL						
6	2	ASSEMBLY													
		BENDING					NIL								
		ASSEMBLY													
7	1	PART	PARALLEL PART FROM PLATE	NON PARALLEL PART FROM PLATE	INTERNAL PART FROM PLATE	PART FROM ROLLED SHAPE	OTHER	BENDING		NIL		PART CODE	PART CODE	STAGE CODE	
								MARKING & CUTTING							
								PLATE JOINING		NIL					

Note: "Nil" indicates no product aspect exists.

Figure 2.12 HBCM Classification by Product Aspects [55]

nization are sometimes called pallets. Pallets sequenced in the order they are built make up the ship's outfitting plan.

On-unit outfitting refers to a zone which defines an arrangement of equipment and supporting structure which is assembled independent of hull structure. On-block outfitting refers to the assembly of equipment on any structural subassembly (semi-block, block, or grand block). On-board outfitting refers to assembly of equipment during or after hull erection and launching. A zone for on-board outfitting is usually defined by a compartment, shell, bulkhead, or deck. In general, on-unit outfitting is the safest and most efficient, followed by on-block outfitting, and finally on-board outfitting. Every effort is made to minimize the amount of on-board outfitting.

Maximum productivity is achieved when work is equally apportioned to work packages grouped by product aspects at the most efficient manufacturing levels and uniform and coordinated work flows are maintained. Other considerations are shifting work, especially welding, from difficult positions to downhand positions; selecting and designing components so as to maximize on-unit outfitting; transferring work from difficult or unsafe locations to open, spacious, low, and otherwise safe places; and planning simultaneous execution of the maximum number of work packages. These considerations have led to the practice of planning outfitting in six manufacturing levels as shown in Figure 2.13.

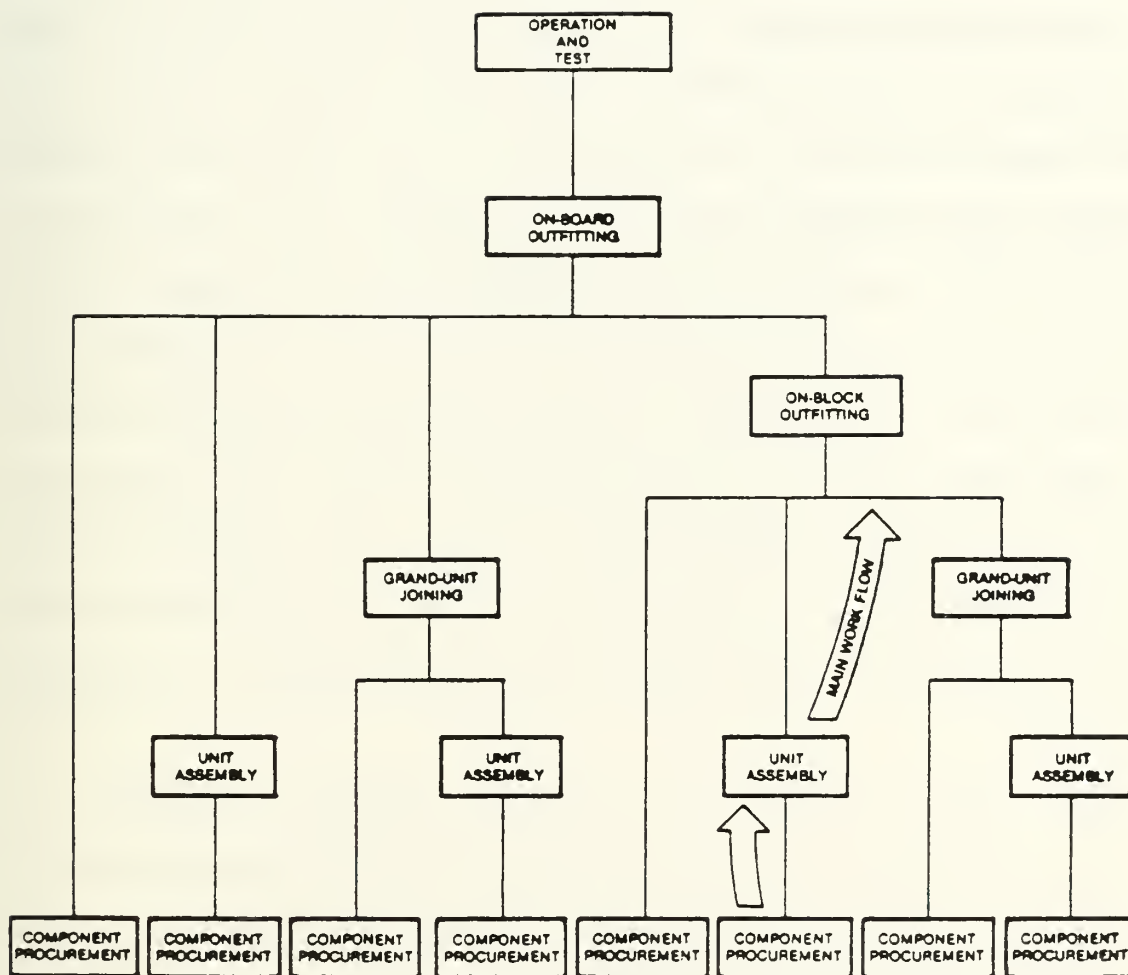


Figure 2.13 ZOFM Manufacturing Levels [57]

As in HBCM, interim products with similar product aspects are grouped to further modularize the production process, justify expensive but highly efficient facilities, and achieve manpower savings. Typical groupings by product aspects are shown in Figure 2.14. It should be noted that these groupings are for a commercial shipbuilding project. For a naval combatant the sixth manufacturing level product aspect area would need to be expanded to include command and surveillance, and armament. Horizontal combinations characterize types of work packages that are required for work to be performed at each manufacturing level. Vertical combinations of work package types denote process lanes for outfitting work flow which correspond to the process flow lanes shown in Figure 2.9. As the use of ZOFG increases, the need for more balanced planning and scheduling, and cooperation among hull construction, outfitting, and painting increases.

ZPTM is a natural consequence of HBCM and ZOFG. Much of the painting work is transferred from the building dock or outfit pier to preceding manufacturing levels by integrating painting with hull construction and outfitting. ZPTM manufacturing levels are shown in Figure 2.15. The prerequisites to successful use of ZPTM are that the painting interval between one coat and the next coat must be shorter than the allowable exposure time for the former coat; each hull block should be virtually finished in order

PLANT LEVEL	MTF LEVEL
1	6
2	5
3	4
4	3
5	2
6	1

PRODUCT ASPECTS						
ZONE	AREA				STAGE	
SHIP	DECK	ACCOMMODATION	MACHINERY	ELECTRICAL	OPERATION AND TEST	
ON BOARD DIVISION	NIL	SPECIALTY/SIMILAR WORK IN SMALL VOLUME	SPECIALTY/SIMILAR WORK IN LARGE VOLUME	SPECIALTY/SIMILAR WORK BY HIGH BULK	WELDING	NIL
					ON-CLOSED-SPACE FITTING	
					WELDING	NIL
					ON-OPEN-SPACE FITTING	
BLOCK	NIL	SPECIALTY/ COMPONENTS IN A LARGE QUANTITY	SPECIALTY/ COMPONENTS IN A SMALL QUANTITY		WELDING	NIL
					ON-FLOOR FITTING	
					WELDING	NIL
					ON-CEILING FITTING	
UNIT	NIL	LARGE SIZE UNIT	NIL		WELDING	NIL
					JOINING	
					WELDING	NIL
					ASSEMBLY	
COMPONENT		IN HOUSE MANUFACTURING	OUTSIDE MANUFACTURING	PURCHASING	PALLETIZING	
					MANUFACTURING	NIL
					DESIGN AND MATERIAL PREPARATION	
						NIL

CODES		
ZONE	AREA	STAGE
SHIP NO	SHIP NO	OPERATION CODE
OUTFITTING SIGN ON BOARD DIVISION CODE	BLOCK CODE	INAIL ERECTION STAGE CODE
OUTFITTING SIGN ON BOARD BLOCK CODE	ON BOARD WORK TYPE CODE	BLOCK ASSEMBLY STAGE CODE
UNIT ASSEMBLY SIGN/BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	GRAND UNIT SIGN
	UNIT SIGN	
COMPONENT CODE/ PALLET CODE	COMPONENT PROCUREMENT SIGN	NO SIGN

Figure 2.14 ZOFM Classification by Product Aspects [55]

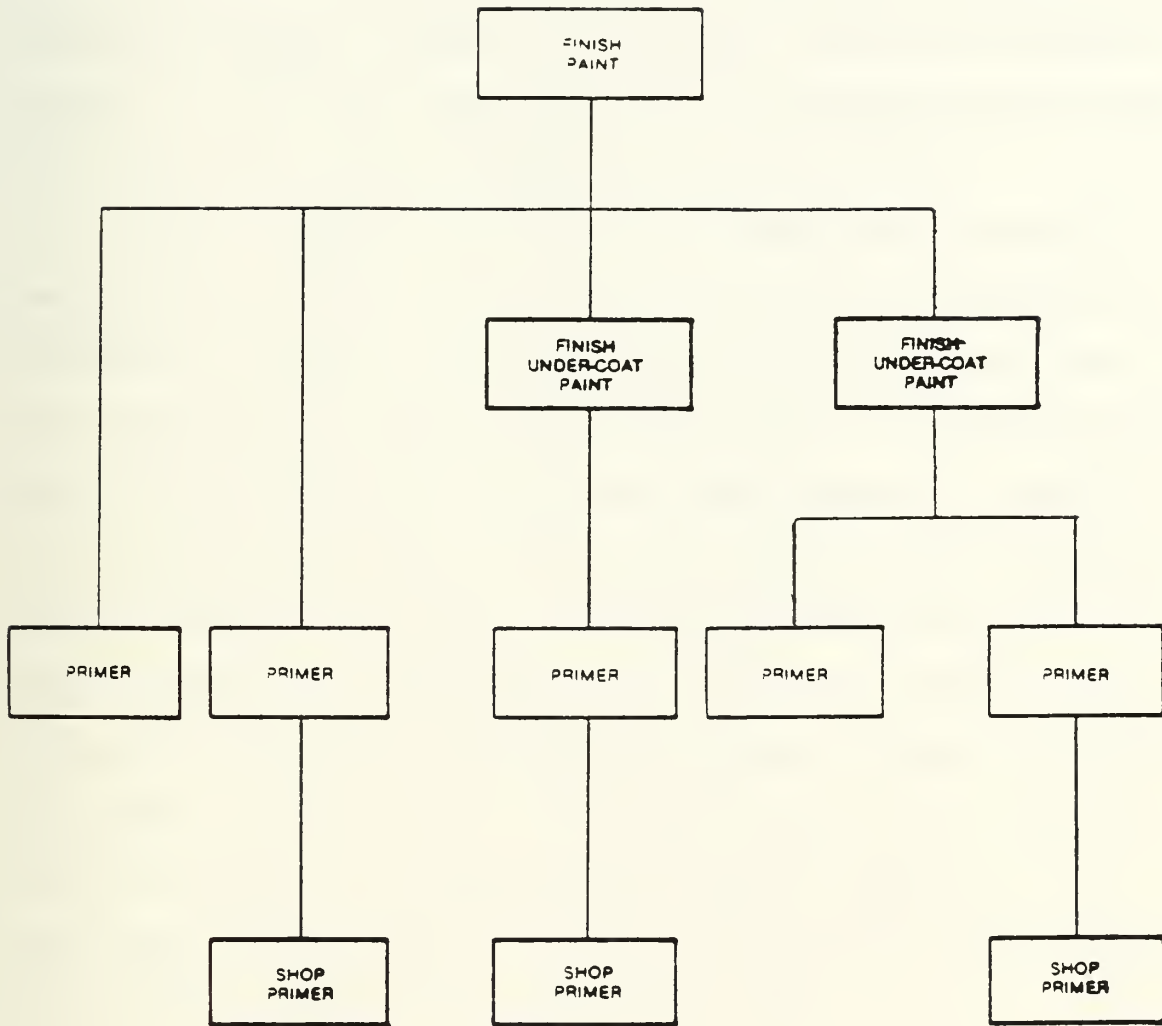


Figure 2.15 ZPTM Manufacturing Levels [57]

to minimize surface preparation and painting rework caused by further cutting, fitting, and welding, and the shop primers applied to plates and shapes should not impede cutting and welding. Managers must ensure effective accuracy control to limit the need for surface preparation and rework resulting from inaccurately made interim products.

The main objectives of shifting painting to earlier manufacturing levels are to shift position from overhead to downhand or vertical, from high places to low places, and from confined to readily accessible places; facilitate the use of environment-controlled buildings; provide a safer setting for painting; prevent in-process rust and subsequent rework; minimize the use of scaffolding; and facilitate level-loading work throughout the shipyard. Typical classification of paint work packages by their product aspects are shown in Figure 2.16. Horizontal combinations characterize the types of work packages that are required to be performed at each level. Vertical combinations denote the process flow lanes for painting work flow.

2.3.7 Accuracy Control

A shipbuilding system based on group technology, using a PWBS, and integrated hull, outfitting, and painting, requires good controls on accuracy. An accuracy control system is initially justified by the need to monitor the construction of interim products to minimize delays and re-

PLAN'G LEVEL	M'FG LEVEL
1	4
2	3
3	2
4	1

PRODUCT ASPECTS						
ZONE			AREA	STAGE		
COMPONENT	UNIT TO BE FITTED AT ON BOARD OUTFITTING		PAINT MATERIAL/ NUMBER OF COAT(S) TYPE OF ZONE/ PAINT SCAFFOLD REQUIRED OR NOT	PAINTING		NIL
	COMPONENT FITTED ON BLOCK AT ON BLOCK OUTFITTING			TOUCH UP		
				CLEANING		
				SURFACE PREPARATION		
	NIL		PAINTING ON BOARD DIVISION	PAINTING AFTER OVERTURNING		NIL
				TOUCH UP AFTER OVERTURNING		NIL
				CLEANING AFTER OVERTURNING		NIL
				SURFACE PREPARATION AFTER OVERTURNING		NIL
				PAINTING		
				TOUCH UP		
				CLEANING		
				SURFACE PREPARATION		
	BLOCK		PAINT MATERIAL/ NUMBER OF COAT(S) TYPE OF ZONE	PAINTING AFTER OVERTURNING		NIL
				CLEANING AFTER OVERTURNING		NIL
				SURFACE PREPARATION AFTER OVERTURNING		NIL
				PAINTING		
CLEANING						
SURFACE PREPARATION						
MATERIAL	NIL		PLATE	PAINTING		
				SHOT-BLASTING		
SHAPES AND OTHER		SHAPES AND OTHER	PAINTING			
			SHOT-BLASTING			

CODES		
ZONE	AREA	STAGE
FINISH PAINT SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS	STAGE CODE OF HSCM, ZOPM, OR PPFM
FINISH UNDER-COAT PAINT SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS	
PRIMER SIGN/ ZONE CODE	PAINT CODE/ NUMBER OF COATS	
SHOP PRIMER SIGN/ ZONE CODE	MATERIAL CODE	

Figure 2.16 ZPTM Classification by Product Aspects [55]

work during erection. However, when fully operational, accuracy control forms a major part of the total shipbuilding system. It involves the regulation of accuracy as a technique for improving shipbuilding productivity by focusing attention on areas where improvements offer significant benefits. It also provides the means for monitoring work by individual work process or problem area. A fully implemented accuracy control system establishes a quantitative feedback loop between production and planning, design, and engineering.

The use of the statistical quality control methods developed by Deming in the 1940's (see Section 2.2) is an essential element in an accuracy control system. Accuracy control should not be confused with quality assurance. Accuracy control is the regulation of accuracy in order to achieve maximum productivity. This involves a trade-off between better accuracy and the downstream improvement in assembly and erection, and the cost to achieve such accuracy [58].

This chapter has provided background and laid the foundation upon which the rest of this thesis is based. We are now ready to discuss the ways in which modern ship production methods have affected naval ship acquisition practices.

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CHAPTER 3
MODERN SHIPBUILDING
AND NAVAL SHIP ACQUISITION PRACTICES

3.1 Introduction

This chapter considers the consequences of modern shipbuilding methods on the naval ship acquisition process as well as the influence the U. S. Navy has on shipyard practices. The particular areas considered are design and engineering, CAD/CAM, ship work breakdown structures, and cost and schedule control systems. It is important to remember that the information in Section 2.3 was presented from an idealized and generic point of view, as seen by the researchers and authors of the various National Ship Research Program's publications. The information presented in this chapter will relate how real implementations of group technology shipbuilding in U. S. shipyards interact with the U. S. Navy and its ship acquisition process. This will be accomplished in both a general way as well as in a specific way by considering examples from actual shipbuilding programs in specific shipyards.

3.2 Design and Engineering

Section 2.1 of Chapter 2 discussed ship design and engineering as viewed by NAVSEA. Section 2.3 of Chapter 2 discussed this topic from the perspective of a group tech-

nology shipbuilder. Application of group technology principles requires alterations in the conventional ship design and engineering process. This section provides a description of the design and engineering process associated with group technology shipbuilding, with particular emphasis on that portion of the process which is under NAVSEA control.

3.2.1 Group Technology Design and Engineering - General Concepts

The principal output of the design process for a conventional shipbuilder is a set of detailed plans and specifications which are suitable for use by any shipyard. On the other hand, the outputs for a group technology shipbuilder are unique work instruction packages that provide specific information for construction organized by the problem areas defined by an individual shipyard. Also, the modern process must allow for timely identification of material and production requirements to enable the shipyard to procure, plan, and schedule in a manner consistent with its management and building strategy. Figure 2.7 showed the management cycle proceeding from system to zone and then back to a system orientation. Design and engineering follow a similar pattern. The design stages employed in group technology shipbuilding were shown in Figure 2.8 and include basic design, functional design, transition design, and work instruction design.

In the Navy context, basic design includes the design iterations up through contract design. This is shown in Figure 3.1. Significant differences from conventional design are the elimination of many expensive and time-consuming system arrangement drawings, identification of outfit work packages by product aspects on composite drawings, the terminology used, and the organization of design stages. The four design stages are described as follows:

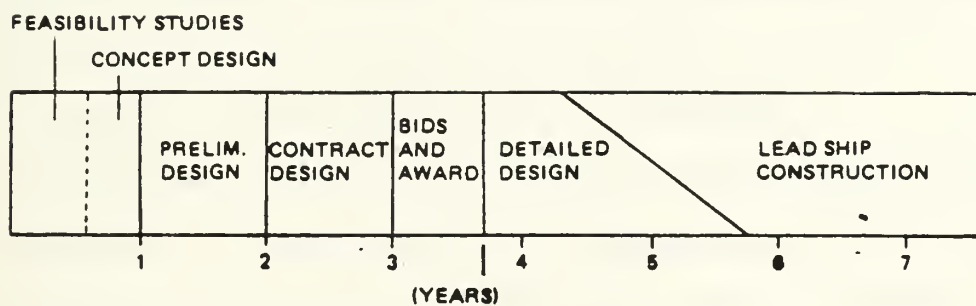
Basic Design describes a ship as a total system. It is based on Navy requirements which fix what the ship is to be and how it is to perform. The end products are specifications and contract plans which vary greatly in thoroughness and detail, depending on the program's acquisition strategy.

Functional Design addresses each system in quasi-arranged diagrammatics for piping and wiring and in system plans. These diagrammatics are sufficient for Navy approvals and are called key plans. A material list by system (MLS) is prepared for each key plan.

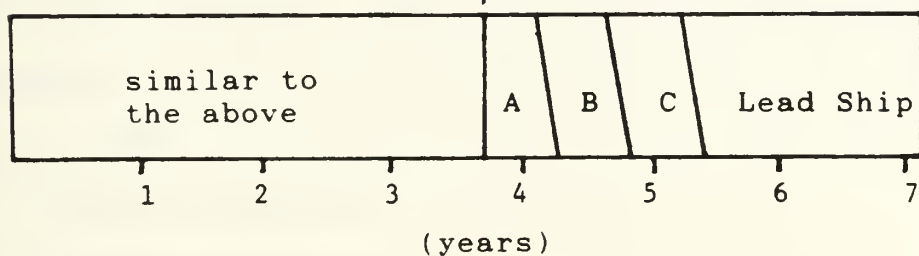
Transition Design regroups information organized by systems into information organized by zones. This first interrelationship of systems and zones, drawn on yard plans, is needed for the development of work instructions.

Work Instruction Design groups design information by additional product aspects, problem area, and stage, which are specific to a given shipyard's manufacturing processes. A material list for fitting (MLF) is prepared for each fit-

Conventional-



Group Technology-



A - Functional Design

B - Transition Design

C - Work Instruction Design

Figure 3.1 Conventional vs. Group Technology Design and Engineering

ting work instruction. A material list for manufacturing a pipe piece (MLP) or a material list for manufacturing any other component (MLC) is prepared for each manufacturing work instruction [1].

In addition to the altered design process and the differences between group technology shipbuilding design and conventional design already described, other major characteristics of group technology design are:

- * greater engineering detail is required
- * design and engineering must be completed earlier
- * material definition must be completed earlier
- * greater coordination with production is required
- * design and assembly details should be standardized.

Additional information must be provided by engineering and the design must take into consideration additional factors.

These include:

- * assembly sequences
- * welding sequences
- * tolerances, excess and edge preparation
- * coating requirements
- * subassembly, unit and block interfaces
- * special tools needed for production
- * work sites
- * structural integrity of subassemblies, units and

blocks, both upright and upside down

- * support and pick points for moving and turning sub-

assemblies, units and blocks

- * minimization of distortion of subassemblies, units and blocks during turning and moving.

Some of this information may be provided by other shipyard groups, such as mold loft, planning, or production, but greater detail and more documentation is required than for conventional shipbuilding. Overall, the engineering effort is more intense in a group technology environment.

The Navy's principal influence in ship design and engineering occurs during the basic design stage. It is therefore worthwhile to examine this stage in more detail in order to discern the interactions that do, or should, occur between the Navy and its shipbuilders early in a shipbuilding program.

Contract plans and specifications are the output of contract design, which is the last stage of basic design. These documents provide a general overview of the ship to be built and, as such, represent the ship in a systems orientation. Among the documents developed are:

- * general arrangements,
- * ship's lines,
- * midship section,
- * machinery arrangement,
- * other specific space arrangements,
- * diagrammatics of major systems,

- * electric one-line diagrams,
- * contract specifications.

Also, as part of the feasibility, preliminary, and contract design processes, normal naval architectural calculations are performed. Among these are:

- * weight estimates,
- * longitudinal strength,
- * Bonjean curves,
- * tank capacities,
- * hydrostatics,
- * intact trim and stability,
- * damaged stability,
- * loading conditions,
- * wake survey,
- * resistance,
- * electric load analysis,
- * HVAC analysis,
- * propeller design,
- * shafting arrangement.

Development of the building strategy is also considered during basic design. This involves preliminary determination of the block plan, the breakdown for outfitting on-unit, on-block, and on-board, and the preliminary determination of the outfit pallet list.

In a preliminary way, basic design:

- * defines simple, logical block boundaries,

- * defines blocks of maximum size and weight allowed by the yard's lifting and moving facilities,
- * minimizes the number of blocks needed,
- * minimizes scaffolding, lifting, and turnovers,
- * identifies zone, problem area, and stage classifications for organizing work flows.

The block pre-definition mentioned above considers how to efficiently fit components and machinery into compartments; arrange deck machinery, mooring fittings, etc.; and perform as much painting as possible before hull erection.

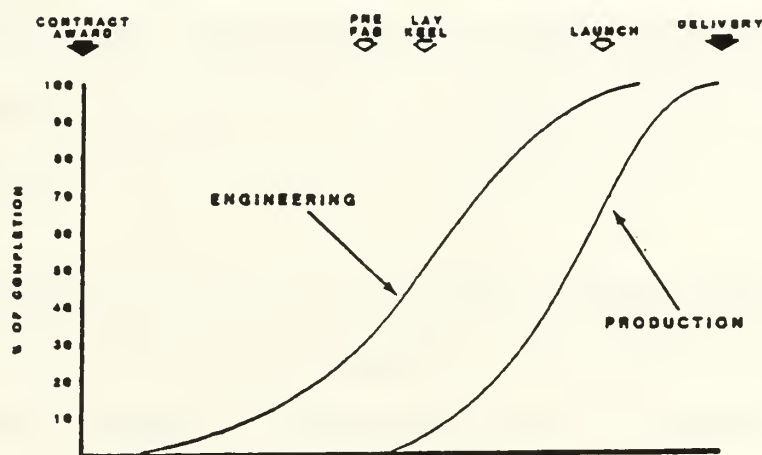
Basic design is also concerned with the development of procurement specifications for long lead time and other important outfit items. These include main engines, power generating equipment, electric motors, steering gear, nuclear propulsion equipment (in the case of a nuclear-powered ship), and combat system equipment [2].

3.2.2 Group Technology Design and Engineering - Examples

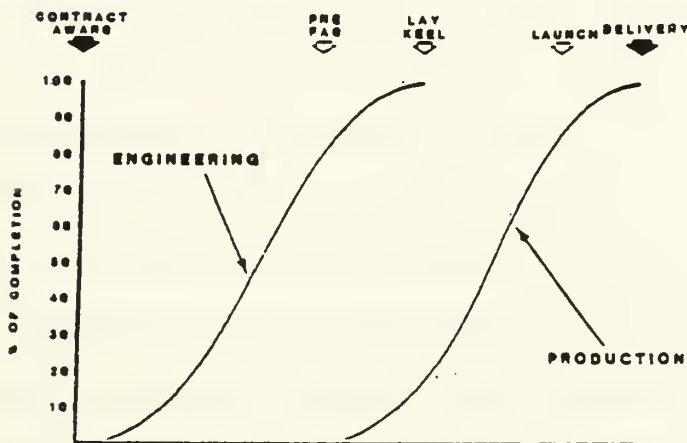
We have seen that there is an intensification of the engineering effort in a group technology environment. Table 3.1 summarizes this effect for the Navy's TAO 187 shipbuilding program. The numbers for conventional construction were estimated through discussion with Avondale Industries' Shipyard Division chief engineer during the TAO 187 program [3]. The group technology-related numbers were provided by Avon-

	Conventional Construction	Group Technology Construction
Total engineering man-hours	520,000	740,000
Percent complete at fabrication start	40	80
Months from contract to fabrication start	19	17
Man-hours per month prior to fabrication start	10,900	34,800

Table 3.1 Engineering Efforts for the TAO 187 [3][4]



COMPARISON OF ENGINEERING DRAWING EFFORT
VS PRODUCTION CRAFT EFFORT UTILIZING
CONVENTIONAL DESIGN AND CONSTRUCTION METHODS



COMPARISON OF ENGINEERING DRAWING EFFORT
VS PRODUCTION CRAFT EFFORT UTILIZING
CURRENT ASI DESIGN AND CONSTRUCTION METHODS

Figure 3.2 Avondale Industries' Design and Construction Methods, Conventional vs. Current [5]

dale's Program Services Division. [4] As can be seen in this table, the intensity of the engineering effort more than tripled with the application of group technology methods. Figure 3.2 further demonstrates this. Of course, the extra expense involved in this higher intensity effort is worthwhile only if savings greater than the extra engineering expense are realized in the course of the production effort. The shortened production period and earlier delivery date shown when using Avondale's current methods indicate this was indeed the case for the TAO 187. See Figure 3.2 for details.

Theoretically, most or all of basic design should be completed prior to contract signing. This poses a problem for naval ship acquisition managers since the shipbuilder is not determined until after contract design is completed and much of the work done during basic design assumes a specific shipbuilder has already been selected. Attempts were made to solve this problem in the DDG 51, SSN 21, and TAGOS 19 programs and these will be discussed later.

The machinery arrangement drawings for the TAO 187 were provided as contract guidance drawings and required modifications to suit Avondale's construction methods and producibility improvements. These changes included:

- * revisions to suit the main engine purchased in lieu of the engine assumed in the contract guidance drawings,

- * revisions to built-in tankage to suit system developments,

- * improved functional grouping of auxiliary systems and components,

- * development of package unit boundaries to suit overall arrangements and construction sequence,

- * minimizing equipment mounted directly on curved side shell,

- * integration of ventilation and wireway routings into space arrangements,

- * integration of access and handling of main engine special tools and spares into space arrangements,

- * detailed development of systems to enable racking of pipe runs, grouped deck and bulkhead penetrations, etc. [6].

Consideration of accessibility for operation and maintenance of all components throughout the ship's life was a primary objective throughout the design process. This consideration was consistent with basic shipyard producibility considerations in that the greater the ease of accessibility in the ship the greater the shipyard productivity.

Table 3.2 summarizes the results of various producibility and productivity measures undertaken in the machinery spaces of the TAO 187. It should be noted that some weight impacts are positive and some are negative. Although no proof was offered, it is Avondale's position that the sum of the weight impacts did not adversely affect the ship [7].

<u>Attribute</u>	<u>Result</u>
Weight	15% increase in foundation weight
Pipe Footage	5% decrease in piping footage
Accessibility	Improved
Operability	Improved
Maintainability	Improved
Construction Cost	15% - 20% reduction
Construction Schedule	Machinery Space Equip- ment and System Installation not on the critical path of ship construction

Table 3.2 TAO 187 Machinery Space Design and Construction Results [7]

When most or all of the drawings in the Navy's contract design package are provided for "guidance only", the contractor has the maximum latitude for developing the detailed design that best accommodates his build strategy and shipyard capabilities. However, there is a growing trend for the Navy to make drawings in the contract design package contract documents. This was true in the LSD 44 program and is now true in the AOE 6 program. Such drawings, which have not had the benefit of producibility considerations, will result in higher ship construction costs, and possible operational limitations and contractual disputes.

In some programs the Navy has tried to come to grips with this problem. These programs include the DDG 51, SSN 21, TAGOS 19, and LSD 44 (Cargo Variant) programs. For the SSN 21 basic design phase there were only two qualified shipyards and both participated heavily in preliminary and contract design. For the LSD 44 (Cargo Variant) program, NAVSEA awarded a contract for contract design to Avondale Industries. Producibility, at least from Avondale's perspective, was thus assured to some degree. But since this is basically a modified repeat design, there are still many of the original contract drawing problems. Also, Avondale's final design product had to be sufficiently general to ensure other shipyards could bid on the detail design and construction contract on a competitive basis with Avondale.

In the DDG 51 program, a great deal of industry input

was requested prior to and during contract design. The various contractors were compensated for their efforts, but only at a minimal level. Most spent far more than they were paid for their efforts, considering it a calculated business investment. In the end, one contract design package was developed and it incorporated many producibility ideas, but due to the competitive nature of the following detail design and construction contract, no one shipyard's proposals could be exclusively followed in the producibility area. Also in spite of the open and generally productive atmosphere the DDG 51 contract design was conducted in, it is probable that some shipyards kept some of their best producibility ideas to themselves and would have incorporated them into the design only after winning the detail design and construction contract.

In the DDG 51 program two of the main basic design participants, Bath Iron Works and Ingalls Shipbuilding Division of Litton Industries, won the lead and follow yard contracts, respectively. In the TAGOS 19 program, the basic design was carried out in a manner similar to the DDG 51's. However, none of the seventeen initial participants in the basic design process won the competition for the detail design and construction of the first ship. This situation will certainly not encourage shipbuilders to use their best talent to assist in similar basic designs in the future, especially when the compensation provided in these programs

has been minimal.

3.2.3 Group Technology Design and Standardization

Standardization is the principle of design for production that could theoretically lead to the greatest improvements in productivity [8]. The discussion of group technology and PWBSs has emphasized the concept of organization of work by problem area. The ultimate goal is to develop a group of standard building blocks that can be combined to produce very different final products.

Efforts at standardization are usually concentrated at the component, subassembly, block, and outfit unit levels. Standards may be classified in two groups [9]. These are basic standards and standard drawings. Basic standards include material and component standards, outfitting standards, design standards, production engineering standards, and inspection standards. Standard drawings show typical subassemblies and outfit units that may be used directly on new designs or as guidance in preparing new drawings. Figure 3.3 organizes this classification of standards in more detail.

Figures 3.4, 3.5, 3.6, and 3.7 are simplified examples of standard drawings for a structural subassembly, machinery arrangement, piping layout, and outfit unit, respectively.

The widespread use of standards is easier to realize in

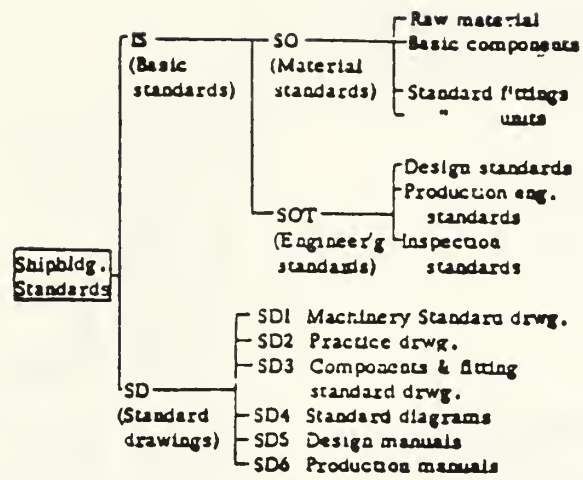


Figure 3.3 Classification of Standards [9]

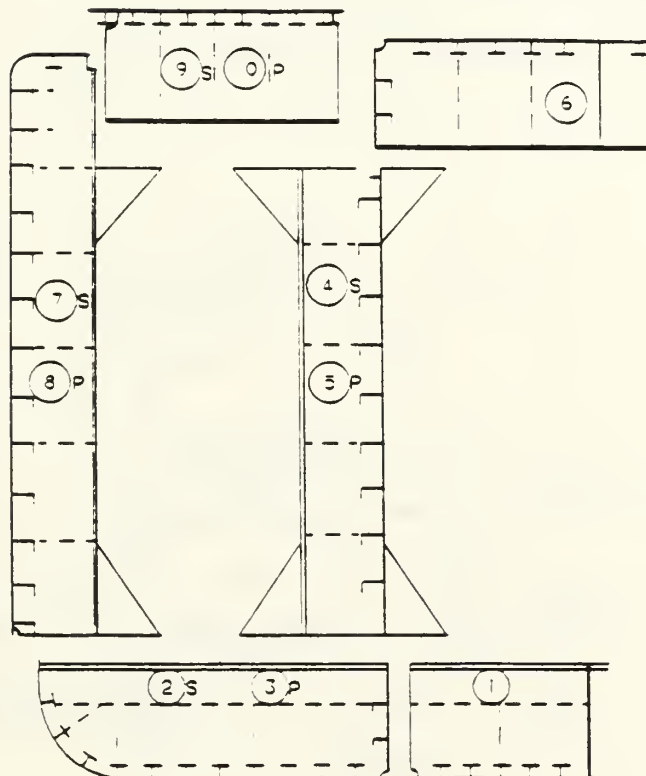
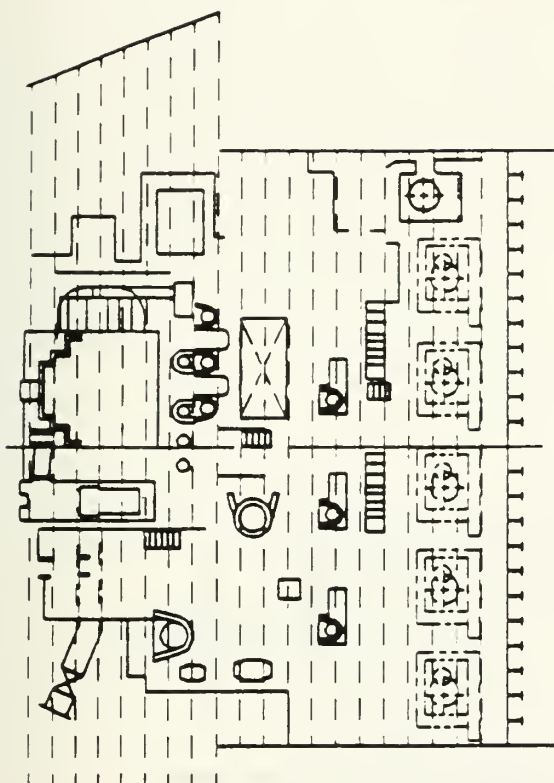
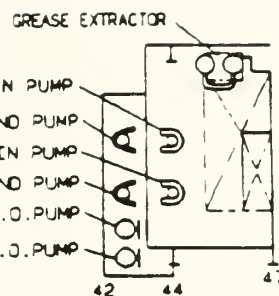


Figure 3.4 Standard Structural Assembly Detail [8]

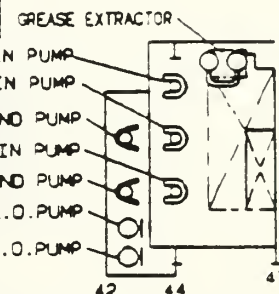


FLAT NAME	DIVISION
MAIN FLOOR	F42-47



(A) BASE MODULE

FLAT NAME	DIVISION
MAIN FLOOR	F42-47



(B) MODIFIED MODULE

Figure 3.5 Standard Machinery Arrangement Module [8]

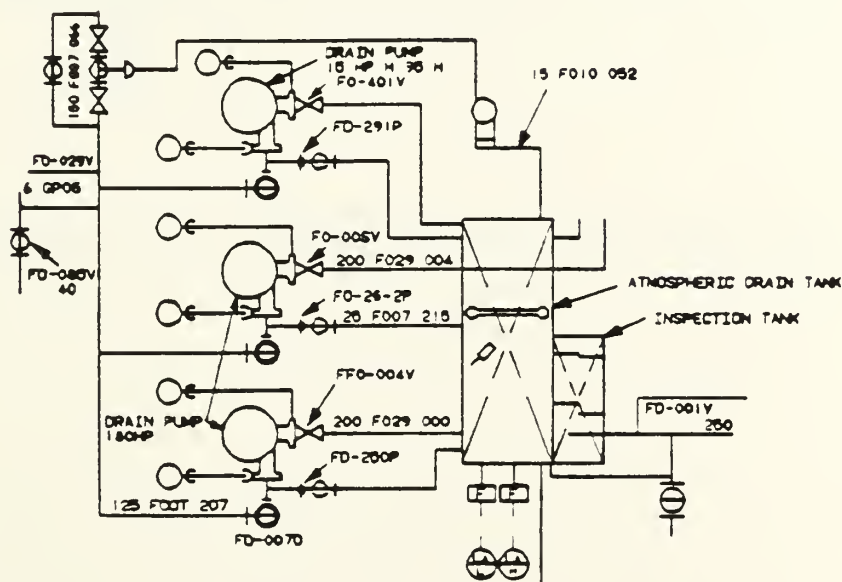


Figure 3.6 Standard Piping Layout Module [8]

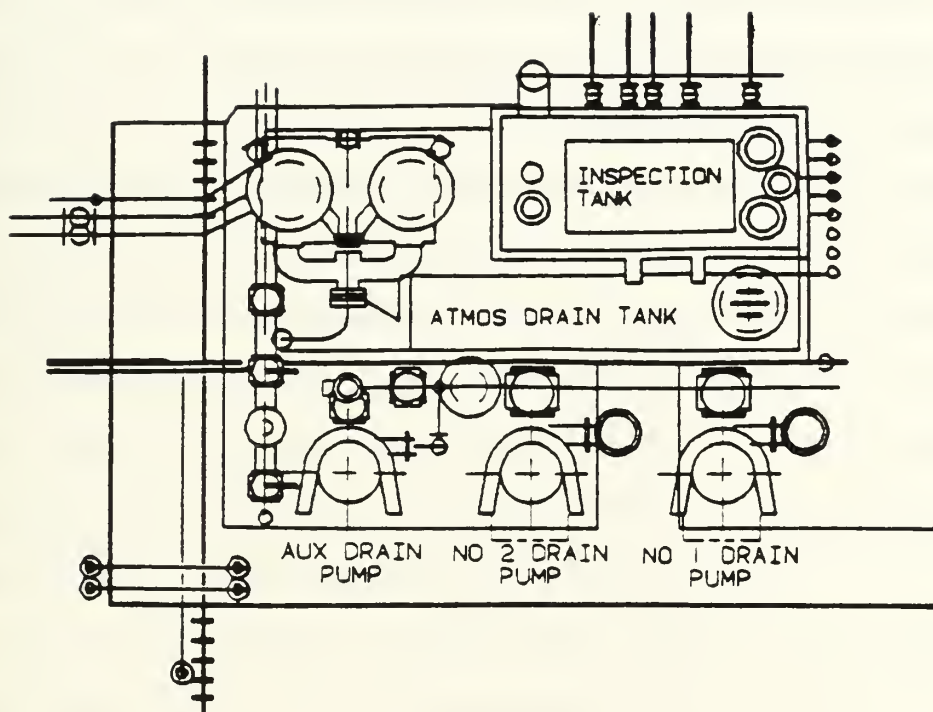


Figure 3.7 Standard Outfit Unit Module [8]

commercial ship design and construction than in naval ship programs. Over the years numerous Military Specifications (MILSPECs) and Military Standards (MILSTDs) have been developed and routinely invoked in shipbuilding contracts. At the time each was developed it responded to some real or perceived need which resulted from a battle casualty, equipment failure, personnel casualty, or similar problem. Unfortunately, over the years not much effort has gone into reviewing these MILSPECs and MILSTDs for current usefulness and they have proliferated to the point where the whole system has become unmanageable and to some extent, outdated. There are numerous examples of MILSPECs which are still in effect simply because they proved useful decades ago. Few attempts have been made to update them after new materials, technologies, or processes became available.

If, for example, a shipbuilder wished to use some new structural detail or welding process which would enhance producibility and reduce construction costs, the shipbuilder would typically bear the responsibility, risk, and cost for shock qualifying or otherwise obtaining approval of the new detail or process. And then, even if this is done, the approval is typically restricted to the class or type of ship for which the approval was originally requested. In such an environment, where contractors have little incentive to improve the system, it is not surprising that attempts at achieving standardization are few [10].

3.2.4 Design Changes in a Group Technology Engineering Environment

Design changes in naval ship acquisition programs are very common. In fact, to deal with the large volume of changes frequently encountered in a major combatant program, the Navy has developed an extensive system which is more or less standardized across various shipbuilding programs.

Design changes occur for a variety of reasons and can be broadly broken down into two categories: changes that occur due to Navy actions and changes that occur due to contractor actions. These include:

- * Navy

- correction of errors discovered in specifications or contract drawings

- correction on follow ships of problems uncovered during operation of the first ship of a class

- the desire to continually incorporate the latest technology in combat systems and other ship systems

- different thinking and new preferences that develop over time

- application of new rules and regulations

- new interpretations of existing rules and regulations

- application of recommendations received after contract award

* Contractor

- revised fitting stages
- revised equipment or component locations
- revised manufacturing process
- revised material availability or sources
- revision of hull structure
- resolution of a design reservation.

A number of contractor changes are the inevitable result of the calculated risk of allowing each of the outfit design groups to simultaneously conduct functional, transition, and work instruction design. Certain aspects of the design progress conditionally, pending the resolution of interference problems.

There is no doubt that group technology ship design and construction is a much more change-intolerant environment than conventional shipbuilding was. This is an anticipated and natural consequence of a system that requires much more documentation and, at the work instruction level, much more paperwork in order to construct a ship. Also, the timing and intensity of the engineering effort tend to make design changes more expensive and have a greater impact on the total effort. This greater expense and impact on the shipbuilding program is justified only if the downstream savings in ship construction costs and shorter construction schedules more than compensate for the greater expense and impact

of design changes.

In the TAO 187 program a special effort was made to hold the number of contract changes to a minimum. Items that were "nice to have" but not essential were not considered. Also, since the TAO 187 is an auxiliary ship and not a combatant, there is less of a concern with achieving the state-of-the-art. There is also traditionally less Navy oversight of auxiliary ship programs and so there are fewer possible inputs for changes. To accommodate the few changes that did occur (in the neighborhood of 100 [11]) a streamlined change control process was instituted. This mainly involved the NAVSEA program office giving more authority to the local Supervisor of Shipbuilding, Conversion, and Repair office for negotiating contract changes. As a result, the impact of changes on the TAO 187 program was minimal and the first four ships of this class were delivered on schedule and at or under budget. This was true even though Avondale Industries has possibly the most advanced implementation of group technology shipbuilding in the U. S. and is therefore presumably the most change-intolerant.

In the CG 47 and DDG 51 Aegis shipbuilding programs the impact of changes has been much more severe. The CG 47 program has had literally tens of thousands of changes to date. The large number was mainly due to the parallel design efforts involved in the shipbuilding program and the Aegis combat system development. Since the combat system

was planned for installation in an existing hull (DD 963 design), the number of changes was actually less than otherwise might have been expected. The effects of these changes on the contractors' shipbuilding systems were mitigated by the fact that neither Aegis shipbuilder had a fully developed group technology-related system at the start of the Aegis shipbuilding program.

The same conditions do not exist in the DDG 51 program. This program features a new hull design coupled with the existing, but still very much developing, Aegis combat system. The number of contract changes are expected to rival that of the CG 47 program. To study the potential impact of these changes, a study was made of representative changes in the CG 47 and DDG 51 programs at both Bath Iron Works (BIW) and Ingalls Shipbuilding (IS). The purpose of the study was to obtain some measure of the engineering impact of changes in a group technology environment.

BIW claims to have essentially a fully implemented group technology shipbuilding system for the DDG 51 program, while IS's system is not so fully developed. The changes selected for evaluation were from among those that were essentially the same for both the CG 47 and DDG 51 programs from a production and ship impact standpoint. This allowed for the comparison of engineering man-hours between the same changes in the two yards to be used as a valid basis for measuring the differences between the two yards' engineering

departments.

The changes considered were:

- * addition of a light to the Officer of the Deck's (OOD's) stand on the bridge
- * increasing power of the weapons pallet truck by changing the power supply voltage from 12 to 24 volts
- * replacing the existing rudder stock seal with a new type of seal to prevent leakage problems
- * changing the control system for the ship's vertical package conveyor system
- * permanent installation of a strain gage shaft alignment system
- * changing the gasket material in some fuel oil and lube oil piping [12].

Table 3.3 gives an indication of the engineering impact of these changes in a group technology engineering environment. No multi-system, single zone change was found. Such a change could be the addition of a damage control locker to the ship. One zone might be affected but numerous piping and electrical systems would need to be rerouted to make room for the space.

A multi-system, multi-zone change will generally have the greatest impact on the engineering effort in terms of man-hours required to process the change in a group technology engineering environment. For this reason the gasket material change will now be considered in detail. It must


	Single System	Multi- system	Single System	Multi- system
	Single Zone	Single Zone	Multi- zone	Multi- Zone
OOD light			x	
Pallet truck			x	
Rudder stock seal	x			
Vertical package conveyor			x	
Strain gage			x	
Gasket material				x
			<hr/>  Direction of greater engineering impact	

Table 3.3 Engineering Impact of Selected Changes in the
CG 47 and DDG 51 Shipbuilding Programs [12]

be remembered that this analysis applies to only the engineering portion of the change.

In April of 1985, NAVSEA directed the replacement of asbestos-filled spiral-wound gaskets with non-asbestos spiral-wound paper/chlorite AMFU gaskets for raised-flange applications [13]. Unfortunately, these gaskets leaked when used in fuel and lube oil systems. Eventually, after partial testing, a decision was made to use non-asbestos spiral-wound graphite-filled gaskets. It is interesting to note that test results did not conclusively confirm that the graphite-filled gaskets will solve the leakage problems and another solution may need to be found in the future.

From a material standpoint this change simply involves substituting one type of gasket for another. The number of gaskets totaled 1415, of 57 different types, ranging in size from 1/4 inch to 10 inches. From a production standpoint, the installation of these gaskets may prove more difficult than for the asbestos-filled ones. This is because a higher quality flange face finish, truer pipe alignment, and greater torque are required to ensure leak-free operation. Generally, these material and production aspects are of equal consequence to both yards. However, the engineering effort, in terms of man-hours required to implement this change, varies considerably from BIW to IS.

Table 3.4 gives a breakdown of the engineering-related man-hours required to implement this change at BIW. A simi-

	Number of Documents	Estimated Man-hours
<hr/>		
"Drawings"	18	280
CAD documents and files	48	3,560
Supervision and staff		516
Checking		430
Production, planning, and control		172
Finance and administration		91
Administrative		225
<hr/>		
TOTAL.		5,274 man-hours
		or 2.54 man-years

Notes: "Drawings" includes actual drawings, BIW engineering standards, and other engineering documents.

CAD documents and files includes CAD system changes, computer data set models, and material lists.

Table 3.4 Engineering-related Man-hours for the DDG 51
Spiral-wound Gasket Filler Material Change [12]

lar breakdown was not available for IS but the total number of engineering-related man-hours required to implement this change was approximately 10% of the total shown in Table 3.4. This large difference for essentially the same engineering change is mostly attributable to BIW's CAD implementation and the expense of altering and reissuing numerous documents at the detail work instruction level. Similar differences for other changes are common in the Aegis program and account for the skeptical attitude toward group technology shipbuilding exhibited by some Aegis program personnel. It is the opinion of the Technical Director for the DDG 51 shipbuilding program that more conventional ship design methods should be used for major combatants, at least for the first few ships of the class. Then, after most changes have been processed, a more economical transition to the work instruction level of detail could be accomplished.

While this approach might reduce the cost of the engineering portion of changes and make them easier to accept politically, it might also have the effect of increasing ship production costs. The cost of engineering changes must be evaluated in the context of the entire shipbuilding program.

3.2.5 Group Technology Design Products

It has been mentioned previously that with the advent of group technology design and engineering, shipbuilders

have been freed from the need to develop individual detail system arrangement drawings. This has caused great concern among some sectors of the NAVSEA ship design community [14]. Traditionally, detail system arrangement drawings have been used for planning future ship alteration (SHIPALT) and overhaul work packages. With these drawings no longer developed by the shipbuilder, some systems engineers believe they will not have the resources required for adequate SHIPALT and overhaul planning. However, the information typically contained in detail system arrangement drawings can be found in detail zone arrangement drawings. In addition, other information not generally found on detail system arrangement drawings, such as system interferences, is available. As a result, detail zone arrangement drawings may prove to be more useful as planning documents than detail system arrangement drawings. The biggest problem will be overcoming the institutional mindset that believes detail system arrangement drawings are necessary [15].

Another problem is concerned with the format of zone drawings. At this time each shipbuilder has his own method of developing them. Typically the drawings include redundant information with both the Navy's and the contractor's nomenclature included. And in some cases, too many systems are included on one sheet of the same drawing. All of this results in cluttered and difficult to read drawings. In order to alleviate these problems the Navy needs to develop

a standardized zone drawing format and invoke it in shipbuilding contracts, as MILSTD 100 and MILSTD 1000 are now invoked [16][17].

3.3 CAD/CAM

Computers were initially used in the shipbuilding industry as accounting tools. Their application has expanded dramatically over the years and the many current uses of the computer in shipyards has expanded beyond the capability implied by the term CAD/CAM. A list of modern computer-aided functions could include:

- * computer-aided design (CAD)
- * computer-aided drafting
- * computer-aided engineering (CAE)
- * computer-aided manufacturing (CAM)
- * computer-aided material definition
- * computer-aided process planning (CAPP).

Other than the above items, computer applications in shipbuilding have grown to include:

- * estimating
- * accounting
- * purchasing
- * numerical control (N/C) operations
- * robotics
- * accuracy control
- * quality assurance

- * inventory control.

As a result, the term CAD/CAM may be somewhat misleading. A more descriptive term is computer-integrated manufacturing (CIM). The major problem now facing shipbuilders in the application of CIM is the lack of a unified shipbuilding data base that provides the capability of interfacing with all the applications mentioned above [18]. The relationship of the data base to the design cycle and its outputs is shown in Figure 3.8. Information required in the data base includes:

- * numerical and geometrical data on past designs
- * weight and space scaling relationships
- * systems and equipment
- * structural design data
- * resistance and propulsion data
- * cost data
- * typical block plans
- * typical outfit plans
- * shipyard and military standards and specifications
- * material lists.

Implementation of a CIM system permits the evaluation of additional design options as well as consideration of alternate building strategies. Computer-generated plans, lists, and work instructions may be used for the various design cycle stages as well as for shipbuilding management functions.

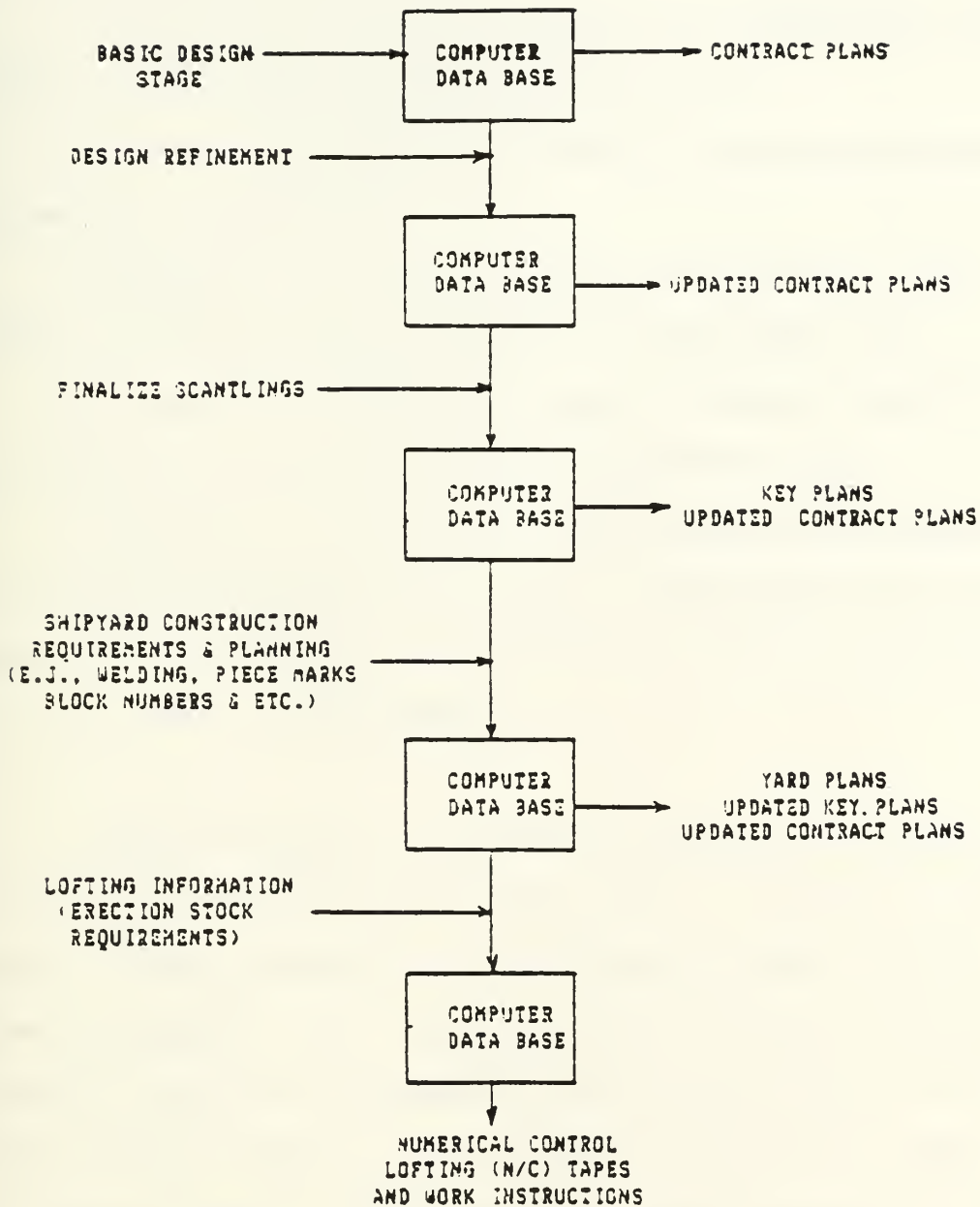


Figure 3.8 The Relationship of a Shipbuilding Data Base to the Ship Design Process [19]

The ultimate goal of a CIM system is improvement in shipbuilding productivity. Among the manifestations of increased productivity are:

- * the ability to produce concept and feasibility ship design studies more quickly and accurately

- * the ability to rapidly evaluate design options and choose the optimum one

- * the ability to perform design calculations with greater confidence due to having a proven data base

- * the ability to transfer data in digital form to shipyard design offices and manufacturing facilities

- * the ability to establish and use shipyard standards.

A coordinated system should lead to simplification of all aspects of the design and production process. See Figure 3.9 for a descriptive summary.

A recent attempt to improve the state-of-the-art in CAD/CAM implementation has taken place in the SSN 21 program. NAVSEA, together with the Electric Boat Division of General Dynamics, Inc. and Newport-News Shipbuilding and Drydock, Inc. have implemented the National Bureau of Standards Initial Graphics Interchange Specification (IGES) on the detail design of the submarine. This allows the two shipyards, with their different and normally incompatible brands of CAD/CAM equipment, to exchange all forms of digital data between their two design departments.

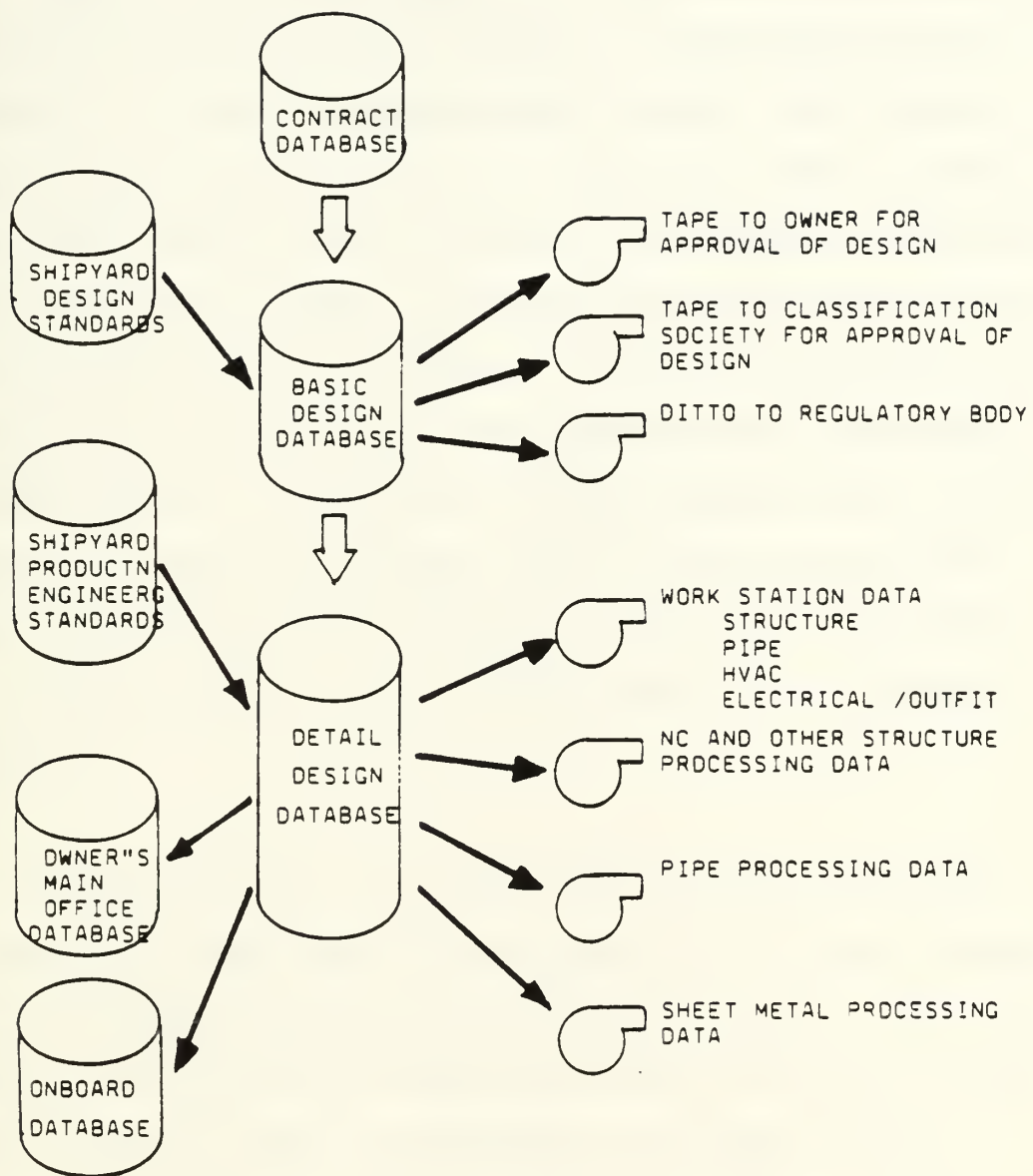


Figure 3.9 Advanced Integrated CAD/CAM Network [19]

As mentioned earlier, a fully developed CIM system requires the development of a unified shipbuilding data base. Part of this development involves the preparation of a "standard library" which contains a considerable level of information covering standard outfit items. This library requires many man-hours and is a task unto itself, necessitating verification prior to using it to prepare interference-free working drawings. Experience has shown that, while optimistic forecasts of advanced CAD/CAM installations have eventually been successful, they have not very often been put into service within their required schedule [20]. Such a realization caused the project team for the Service Life Extension Program for the USS Kitty Hawk (CV 63) to modify its original plans for use of group technology on the program [21].

CAD/CAM projects currently being pursued within the Navy generally fall under the cognizance of the DoD program known as Computer Aided Logistic Support (CALS). CALS was initiated in 1985 by the Deputy Secretary of Defense in an effort to achieve major improvements in weapon system designs, and to improve the accuracy, timeliness, and use of logistic technical information. The ultimate goal is to move from current paper-intensive weapon system support processes to a largely automated and integrated system [22]. Figure 3.10 provides a graphic presentation of a notional

CALS system.

NAVSEA has identified two intermediate goals in support of CALS. They are:

- * identify and specify the digital products that are to be received at the conclusion of each ship acquisition and support phase and

- * have the facilities and software in place to receive those digital products and use them as the basis for all support activities [23].

The principal technical problem to be solved is finding a way for computer communication links to be made among the varied and numerous participants. Figure 3.11 shows a flow chart of the CALS process. The lettered arrows are the communications links. A joint industry/Navy committee has been formed to research this problem. It is called The Navy/Industry Digital Data Exchange Steering Committee. Demonstration data transfer projects are currently underway in the DDG 51 program and, as already mentioned, in the SSN 21 program. These programs have been mainly concerned with the links lettered "A" and "B" in Figure 3.11.

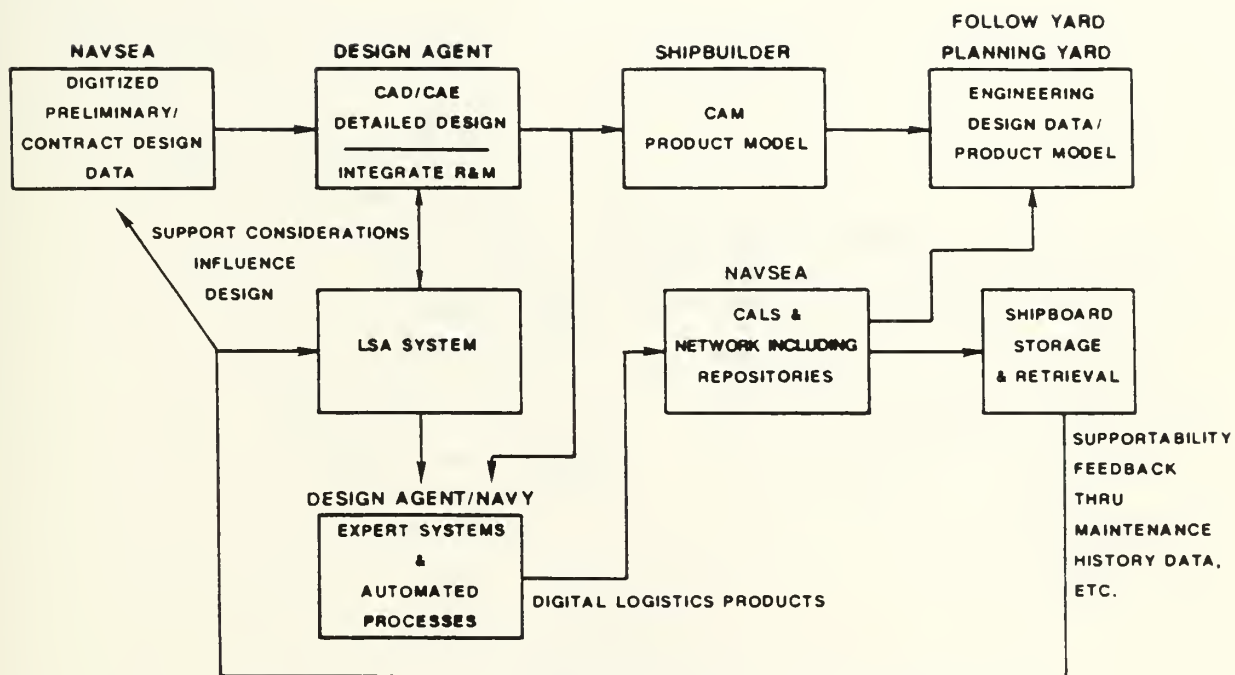


Figure 3.10 Notional CALS System [23]

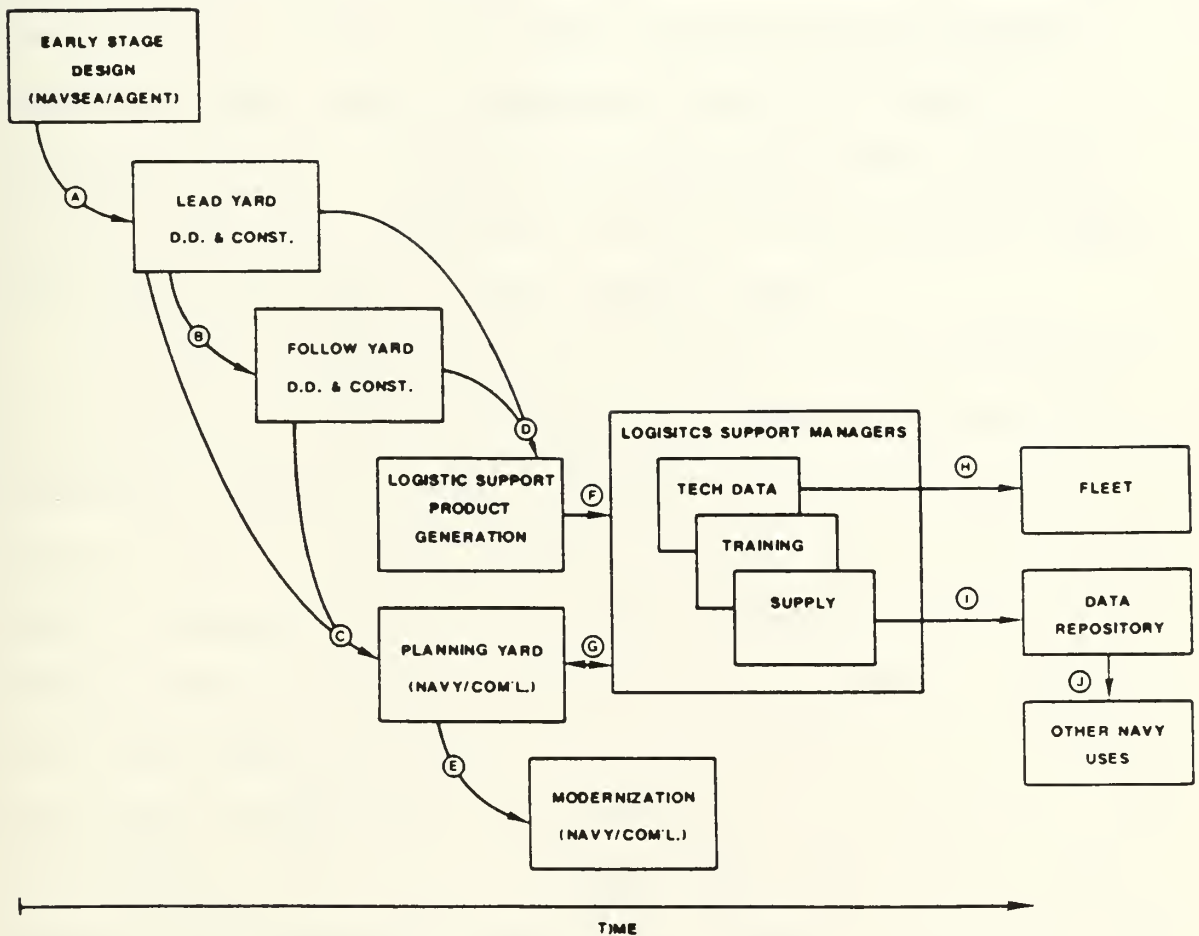


Figure 3.11 Principal Data Transfer Interfaces in a CALS System [23]

3.4 Work Breakdown Structures (WBS) and Cost and Schedule Control Systems (C/SCS)

Navy shipbuilding contracts routinely call for WBSs and require that they conform with MILSTD 881A, which is entitled "Work Breakdown Structures for Defense Material Items". In addition, shipbuilding contracts frequently require adherence to further Navy-defined WBSs. Two that are currently invoked are called the ship work breakdown structure (SWBS) and the expanded ship work breakdown structure (ESWBS). ESWBS was briefly described in Section 2.3.3. Their most important feature is that both are organized along functional or ship system lines.

The WBS that makes the most sense for group technology-oriented shipbuilders, however, is a product oriented work breakdown structure (PWBS). This was described in detail in Section 2.3.3. Further, Chapter 32, Part 196 of the Code of Federal Regulations, entitled "Work Breakdown Structures for Defense Material Items", requires that government contractors have complete flexibility in extending the generic WBSs described in MILSTD 881A (see Appendix A) to reflect how the contractor's work is to be accomplished. This has led some people, both shipbuilder and Navy personnel, to contend that the Navy-imposed SWBS and ESWBS are therefore, at best, unneeded documents, and are, at worst, illegal documents [24].

If this conflict between Navy requirements for a traditional system-oriented WBS and contractor requirements for

a product-oriented WBS, which reflects the way the ship is actually constructed and managed, is not resolved, shipbuilders will continue to manage by one system and report to the Navy by another. The inefficiencies and inaccuracies that result are not only expensive but also lead to the Navy not being able to adequately monitor cost and schedule progress.

The Navy's SWBS was originally issued in March 1973 as a structured system (3-digit numbers providing 5 levels of breakdown) which was intended for use in specification preparation, cost estimating, cost progressing, management, weight control, drawing numbering, shipyard job order coding, and similar purposes. ESWBS provides two additional levels of breakdown of functional systems so that ESWBS can be used for logistic support, maintenance, and life cycle support purposes. ESWBS is now being specified contractually and is used as the basis for C/SCS reporting. Appendix B provides more details.

As described in Section 2.3.3, the PWBS was developed to support group technology shipbuilding. As such, it provides a natural breakdown for schedule reporting and for collection of financial data as required by C/SCS instructions. A shipbuilder's PWBS is hardware or product-oriented, and is consistent with the methods of planning, scheduling, and construction actually being used by the

shipbuilder. Appendix C provides further details.

Effective management control must be based on the items or products produced. The PWBS used on a particular shipbuilding program should be based on the products produced and on the coding system used within the shipbuilder's management structure. For example, on the LSD 44 program at Avondale Industries, Inc., ships are fabricated by assembling units which are numbered from 000 to 799. The units' locations are usually determined by the digit in the hundred's column. Material is scheduled and assembled by unit number and work is budgeted and authorized by units or groups of units. The unit number is the focal point of the PWBS and units are easily summarized by series: 100, 200, etc., for reporting purposes. Where there is a process or effort which spans unit boundaries, the definition of MILSTD 881A are used to define these efforts and are summarized at the series level for reporting. Other activities such as testing, program management, or other services are similarly summarized to coincide with MILSTD 881A definitions at levels 2 and 3. All of the reporting is developed and used to manage, control, and report financial status directly from the labor and material coding used in Avondale's accounting system. If reporting was done based on an ESWBS system, the information would somehow have to be back-allocated into the traditional functional or system categories. This would be needlessly time-consuming and probably inaccurate for both

schedule and cost reporting. Figure 3.12 depicts the physical ship elements of the LSD 44 program contract WBS and Table 3.5 describes all summary elements. Figure 3.13 is a portion of the program's responsibility assignment matrix (RAM). The element numbers in the matrix indicate summary work package numbers. A review of the RAM quickly discloses which work group (with the name of the corresponding work group superintendent) is responsible for its portion of the work in a particular zone or within a particular element.

The initial steps to resolve the conflicts between shipbuilder and Navy desires regarding WBSs have been taken [27]. At an industry conference on WBSs attended by representatives of various shipbuilders, NAVSEA, ASN(S&L), and the Office of the Secretary of Defense (OSD), a decision was made for the industry conferees to submit their requested revisions of MILSTD 881A to the Navy and OSD for review. An ad hoc industry committee was formed and prepared a proposal which was submitted to representatives of OSD, ASN(S&L), and NAVSEA at a follow-up meeting on September 24, 1987 [28]. The recommendations were well-received by the government attendees and a formal response to the industry position was promised by October 28, 1987. Unfortunately, the Navy has been unable to obtain the approval of the other services for the proposed changes to the MILSTD. This stems from the other services' reluctance to approve a WBS which allows

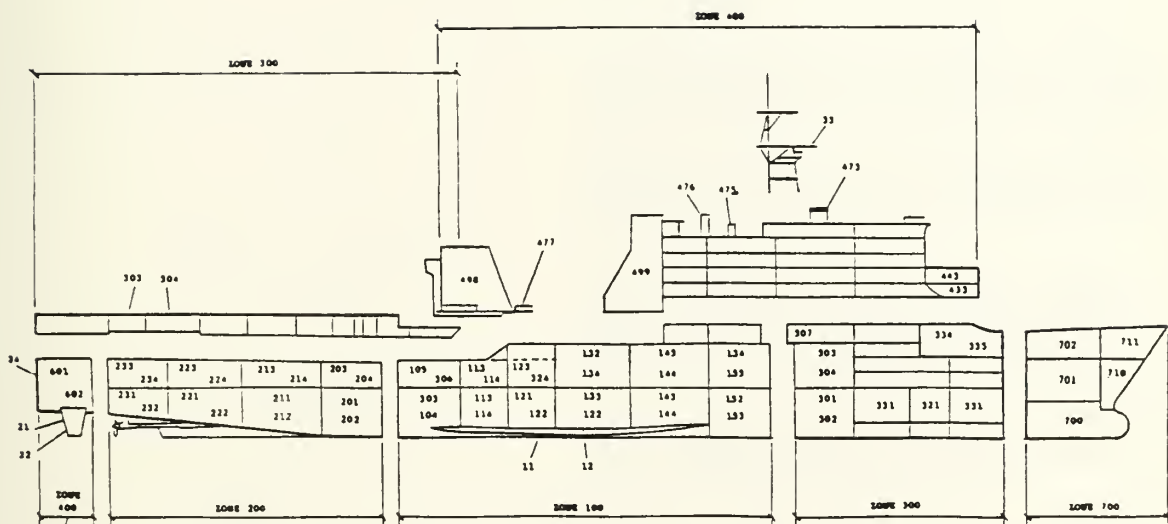


Figure 3.12 LSD 44 Program Contract WBS Physical Elements [25]

Contract WBS Element or Zone	Description
000	Includes units which are special fabrications installed throughout the ship. Work under this element includes material, manpower, inspection test, supervision, and the effort to install government furnished equipment.
100	Includes units between frames 43 and 98 and baseline to the 02 level.
200	Includes units between frames 98 and 137 and baseline to the main deck level.
300	Includes units between frames 13.2 and 43 and baseline to the 02 level.
400	Includes units between frames 13.2 and 92 and above 02 level.
500	Includes units between frames 92 and the stern and above the main deck.
600	Includes units between frames 137 and the stern and from baseline to the main deck.
700	Includes units between the stem and frame 13.2 and from baseline to the main deck.
Ship Assembly	Includes efforts and material associated with the ship as a whole and which cannot be identified with other zones.

Table 3.5 Description of Contract WBS Elements for the LSD 44 Shipbuilding Program [25]

Contract WBS Element or Zone	Description
Integration/ Engineering	Includes labor and material for the design of the ship.
Program Management	Includes efforts and material to provide management necessary to ensure cost, schedule, and technical performance under the contract.
Test and Evaluation	Includes efforts and material to conduct all testing for the ship.
Data	Includes all deliverable data to be submitted, as listed on contract data requirements list.
Spares, Support, Jigs, and Dies	Includes efforts and material necessary to procure, handle, and store spare components, assemblies, repair parts, and special production equipment, etc.

Table 3.5 Description of Contract WBS Elements for the LSD 44 Shipbuilding Program [25]
(continued)

for transitions from a system to a zone and then back to a system orientation. Even within the Navy there is opposition to this process because of fear that every shipbuilder would try to avail itself of a unique cost performance reporting system. It appears at this time that the use of MILSTD 881A as the vehicle to establish the so-called "two track" reporting system may not be feasible. Nevertheless, ASN(S&L) and NAVSEA appear committed to finding a way to facilitate the use of a PWBS. NAVSEA is preparing an internal decision paper on the issue and it is expected in the very near future.

3.5 Learning Curve Effects in Group Technology Shipbuilding

It is widely believed that the group technology approach to shipbuilding is worthwhile for even one-of-kind ships. And, of course, as more ships of the same class are built, further savings accrue due to decreased production costs. But does the data indicate these savings are constant or is there any evidence that savings continue to increase as the number of ships produced increases? In other words, does any "learning" take place? To help answer this question, the TAO 187 shipbuilding program at Avondale Industries, Inc. was considered. Table 3.6 shows the results of examining the cost data summary reports prepared for the TAO 187, 188, 189, and 190. It is clear that some slight benefit arises from series production. As was noted

<u>Ship</u>	<u>Recurring Production Costs</u>
TAO 187	1.000
TAO 188	0.991
TAO 189	0.943
TAO 190	0.938

Note: Data are reported on a relative basis with the recurring costs for the TAO 187 set arbitrarily to 1.000. This was done due to the proprietary nature of the cost data.

Table 3.6 Recurring Ship Production Costs for the TAO 187 Program [29]

earlier, few changes were made during the course of this shipbuilding program. This is the only military shipbuilding contract that has been completed and has used the group technology approach from beginning to end. (More TAOs are being built under new contracts.) It will be interesting in to analyze the return costs for other shipbuilding programs at other shipyards in the future to see if there is evidence of this slight learning trend or if there are more dramatic results.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

As was noted in Section 2.1.6, the strategies used in today's naval ship acquisition programs are decided on a case-by-case basis at the beginning of each acquisition program. The approach taken is articulated in the program's acquisition plan. The technical and managerial complexities associated with the design and construction of modern naval ships make such an approach preferable to the rigid approaches used in the past. This is particularly true today since the building capabilities of potential shipbuilders must be taken into account at the beginning of the program if the Navy is to obtain the best ship for the stated mission in the shortest period of time at the least cost.

The group technology-based design and construction methods employed today by successful U. S. shipbuilders have significant effects on the manner in which NAVSEA approaches its primary task of ship acquisition. It has been argued that in today's technical environment NAVSEA must be aware of the specific capabilities of all of its potential shipbuilders if it is to obtain the best ships for the taxpayers' money. And in today's political and economic environment, with the Navy entering what will undoubtedly be a

period of prolonged budget shortfalls in its shipbuilding program, it is essential that the Navy make every effort to obtain the most "bang for the buck". By encouraging and supporting modern group technology shipbuilding and promoting attention to producibility among its shipbuilders, the Navy will be the ultimate recipient of the benefits which accrue.

Recent design efforts have included attempts to ensure that producibility is given a high priority. The AOE 6 program held several design reviews with prospective shipbuilders to identify producibility improvements in the design. The DDG 51 design had a group of shipbuilders review the design and perform separate studies to evaluate various producibility concepts. The SWATH TAGOS program collocated a diverse group of shipbuilders with the NAVSEA design team and used their suggestions to improve the producibility of the design. The SSN 21 program took steps to ensure that both submarine shipbuilders in this country addressed producibility in their design efforts. All of these efforts have heightened the sensitivity of NAVSEA's designers and the Navy's shipbuilders to designing naval ships with producibility in mind. As indicated earlier, the benefactor of these efforts is the Navy. It has received better ships for fewer dollars in a shorter period of time. It is therefore in the Navy's best interests to do even more to ensure that producibility and the other attendant benefits of group

technology shipbuilding are realized in the future. Specific areas in which the Navy should concentrate its efforts are now suggested.

4.2 Recommendations

As has been discussed, significant advances have been made in implementing group technology methods in naval shipbuilding and in improving the producibility of Navy ships. However, there are specific areas in the naval ship acquisition process where further improvements can be made. These changes and improvements should help to further increase productivity and reduce ship construction times and costs.

In the areas of CAD/CAM, WBSs, and C/SCSs, specific recommendations are:

- * The Computer Aided Logistics Support program deserves strong support from the highest levels in DoD and the Navy. It has great potential for very large cost savings for the Navy.

- * The joint Navy/Industry Digital Data Exchange Steering Committee should be encouraged and their efforts expanded.

- * Efforts to include public shipyards and shipyard equipment vendors in the CALS program and NIDDESC should be encouraged.

* The Navy needs to find a way to facilitate the use of product work breakdown structures among all its shipbuilders. It might be as simple as changing the Cost Performance Reporting Handbook issued by NAVSEA and ensuring that contract requirements are revised to reflect the new systems. If this is not done the Navy will continue to impose needless extra work on its shipbuilders and receive cost and schedule data of doubtful quality and usefulness.

As was pointed out in Section 2.2, the genesis for much of the current progress in naval ship producibility and group technology shipbuilding was the National Ship Research Program (NSRP). This program can continue to save the Navy money in three ways. One is to continue on the present course of solving productivity and producibility problems in new ship construction. The second is to use some of the NSRP initiatives and methodologies in ship repair, overhaul, and modernization. In the years to come new construction will decline and the importance of maintaining and modernizing ships economically will increase. The third area to reap additional savings is in applying NSRP initiatives and methodologies to the Navy's vendor community. Emphasis in the past has been on applying producibility concepts to the prime contractor in a shipbuilding program, namely, the shipbuilder. It is important to remember, though, that today the cost of a modern warship system is divided almost

equally between the ship itself and its combat system and other government furnished equipment. Applying group technology to the vendor community should therefore be worthwhile and should be pursued.

In the Navy's attempts to find ways to save money in the next few years, much attention will be given to justifying current research and development programs. The NSRP is a program which has paid and continues to pay for itself many times over. What it lacks, though, is a program champion to save it from the budgeteer's ax. It is in the best interests of the Navy and the NSRP to correct this deficiency immediately and for the Navy to continue to support the NSRP.

The greatest productivity and producibility gains of the future may come in the area of combatant ship design. This is because this area has historically been the most constrained due to issues of ship safety, survivability, and maintainability. Design practice changes will be driven by the severe cost constraints placed on today's naval ships and by the involvement of shipbuilders in the design process. This involvement has heightened NAVSEA ship designers' sensitivity to the benefits of producibility. NAVSEA must provide designs which enable the application of shipyard producibility expertise.

The conventional wisdom has been that since ship con-

struction facilities and methods vary widely among shipyards, the Navy cannot tailor a contract design for a specific shipbuilder. Perhaps this indicates that the Navy should get out of the contract design business. It might be more advantageous for the Navy to award contract design contracts to all shipbuilders interested in a specific program. Each shipbuilder could then maximize the producibility methods used in its own shipyard and provide the Navy with a contract design which is most economical for it to produce. Such an environment requires that the Navy minimize the number of contract drawings and maximize the amount of information given for guidance only. The increased costs incurred from multiple contract design efforts should be more than offset by the decrease in production costs realized from allowing the winning shipyard to maximize the use of its producibility methods.

It is recognized that this approach may be too radical for the Navy bureaucracy, and in particular for NAVSEA, to accept. Other approaches may be more acceptable. There are many potential early stage design producibility concepts which could be beneficially applied by all modern shipbuilders and these are now suggested.

Contract guidance drawings that identify functionally related package units could be developed as part of the preliminary design process. Basic entities such as fuel oil

pump and heater packages, lube oil filter and cooler packages, auxiliary sea water pump packages, main engine jacket water pump and cooler packages, modularized berthing compartments, etc. are certainly identifiable at early stages of design and, regardless of the shipbuilder selected, the most cost effective and operationally viable arrangement of these packages or systems could be obtained.

Other general concepts have been identified and form a core group of opportunities for enhancing producibility. They should be evaluated in specific designs where they are applicable. They include:

* Hull Form:

- use of parallel midbodies and flat bottoms
- maximum use of flat plates
- minimal use of compound curves
- minimal use of combined shear and camber
- use of flat, rather than curved, transoms.

* Structures (Most suggestions in this area would require significant changes to MILSPECs and MILSTDs, as alluded to in Section 3.2.3):

- maximum use of uniform plate sizes
- use of flat bars or angles as stiffeners
- use of lapped or bracketed end connections for stiffeners
- maximum use of uniform stiffener sizes
- use of flat innerbottoms

- running deck longitudinals parallel to the ship centerline at the bow and stern.

- * Arrangements:

- grouping functionally related compartments together
- as describe earlier, arranging equipment to aid in the preoutfitting of package units.

- * Machinery:

- increasing commonalty of equipment (standardization)
- centralizing parts of a system to minimize piping runs
- using commercial equipment where acceptable
- arranging equipment to allow for installation access.

- * Combat Systems

- using modular systems
- distributing combat system support services vertically using armored trunks.

In order for NAVSEA designers to consider and evaluate producibility concepts, there are certain actions NAVSEA should take. These include:

- * training ship design engineers in modern ship construction practices and producibility concepts (It should be mentioned here that the Education and Training Panel of the Ship Production Committee of SNAME is now in the process

of developing a certificate course in manufacturing engineering and ship production.)

- * developing evaluation methodologies and cost estimating relationships to allow evaluation of producibility concepts during early stage design (The lack of non-proprietary numerical data will make this task difficult and poses a separate problem in itself.)

- * considering changes to the ship design process which will facilitate design for modular construction during early design stages

- * developing standard design practices to include producibility in ship designs

- * developing a lessons learned mechanism that provides feedback or communication with shipbuilders and researchers in the ship producibility area.

It must be kept in mind that design for producibility is only one of many design considerations. Adoption of alternatives for enhanced producibility must be based on analyses of their impacts on other design considerations and life cycle costs. To do this will require knowledge of cost factors and modern ship production technology. For example, it has been suggested that selection of slightly larger ships, which are more producible, is preferable to selection of more costly and less producible, but more compact, ships. This argument implies that heavier systems for machinery or

structure are likely to be chosen in favor of lighter, but less producible, ones. When this situation is evaluated with regard to increased life cycle costs incurred due to propelling a larger, heavier ship through the water for several decades, the ultimate decision might be to use the less producible design. Therefore, producibility concepts which significantly affect ship performance (the heavier ship will also be slower), or which significantly affect other design considerations or life cycle costs, should be evaluated as trade-offs. Other producibility concepts which will reduce the cost of ship construction and which have no significant impact on these other areas should be eagerly accepted and encouraged.

APPENDICES

APPENDIX A

MILSTD 881A (25 April 1975)

Work Breakdown Structures for Defense Material Items

MILSTD 881A is mandatory for:

- All defense material items (or major modifications) being established as an integral program element of the 5-year Defense Plan (FYDP).

- All defense material items (or major modifications) being established as a project within an aggregated program element where the project is estimated to exceed \$100 million in RDT&E financing, and

- All production follow-on of the above.

Functional or System Orientation

- It establishes criteria governing the preparation and employment of WBSs.

- It establishes a standard system-oriented family tree of hardware, services and data.

MILSTD 881A rules and practices include the following:

- A preliminary contract WBS shall be identified in the government's solicitation.

- The project summary WBS is structured by the DoD component.

- The contract WBS will be negotiated with each individual contractor.

- The contractor shall extend the negotiated WBS to lower levels to form a project WBS.

- Contractors may propose changes to the preliminary WBS during negotiation.

- Preordained structure shall not be imposed on the contractor.

- Configuration items will be identified as WBS elements.

- Families of specifications and drawings which result from systems engineering activities shall conform to the evolved project WBS.

- The contract WBS shall serve as a framework for the contractor's management control system which will provide auditable or otherwise traceable summarizations of internal data generated by his performance measurement procedures.

- Integrated Logistics Support shall be accommodated by the summary level WBS.

- Reporting requirements shall be consistent with the contract WBS.

- The lowest level of the extended contract WBS for project planning control and support shall reflect the way the work is actually performed. (This is not possible using SWBS or ESWBS with today's construction methods.)

Summary WBS and Definitions of Ship Systems as Defined
in Appendix E of MILSTD 881A

- Level 1 - Program or contract
- Level 2 - Individual ship plus services
- Level 3 - Systems or functional segments described by
a 3-digit code as described in Table 2.1.

APPENDIX B

S9040-AA-10X-010/SWBS 5D - 13 February 1985

ESWBS for all Ships and Ship/Combat Systems

ESWBS is mandatory for:

- Configuration identification, status accounting, specifications, design, production and maintenance where breakdown below level 3 is specified in a contract.

Functional or System Orientation

- It establishes a standard product-oriented family tree of hardware, services and data down to level 7.

ESWBS rules and practices include the following:

- The contract WBS is identified in the solicitation.
- The project summary WBS is structured by the Navy.
- Preordained structure is imposed for all end items of a program throughout its life (contrary to Appendix A).
- Configuration items will be identified as WBS elements.
- Families of specifications and drawings resulting from systems engineering activities shall conform to the project WBS.
- The contract WBS shall serve as a framework for the contractor's management control system which will provide auditable or otherwise traceable summarizations of internal data generated by his performance measurement procedures.

- Integrated Logistics Support (ILS) shall be accommodated by the summary level WBS.

- Reporting requirements shall be consistent with the contract WBS.

- The lowest level of the extended contract WBS (level 7) for project planning control and support shall reflect the way the work is actually performed.

ESWBS Organization

- Level 1 - Program or contract

- Level 2 - Individual ship plus services

- Level 3 - Systems or functional segments as defined in MILSTD 881A

- Levels 4 through 6 - Functional description of systems/equipments

- Level 7 - Equipment.

APPENDIX C

Product Work Breakdown Structure

National Shipbuilding Research Program

U. S. Department of Commerce Maritime Administration
in cooperation with Todd Pacific Shipyards Corporation

November 1980

PWBS is mandatory for:

- Any large construction project where work must be logically subdivided in order to be readily analyzed and managed.
- Support of zone outfitting and group technology construction methods.

Product Orientation

- The interim product is viewed as the focal point of the PWBS system.
- Classification of products is selected by the individual shipbuilder to provide maximum improvement in productivity using the shipbuilder's facilities.

PWBS rules and practices include the following:

- It conforms with the way the ship is built.
- The focus is on needed parts and subassemblies or the interim products which are required for larger assemblies.
- Interim products are classified by product aspects: system, zone, area and stage as described in Section 2.3.3.

- Use of a PWBS results in natural work packages, ideal for planning, scheduling, and execution.

- Subdivisions are small and facilitate control of work flow and progress reporting.

- Individual shipyards have the flexibility of establishing their own expanded work breakdown structures which can be reflective of the way ships are actually built at that shipyard.

PWBS Organization

- Level 1 - Program or contract

- Level 2 - Individual ship plus services

- Level 3 - Interim products (units, modules, zones or processes, etc.)

- Levels 4 and beyond - components, subassemblies, processes or activities, as required.

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